PRACTICAL USE OF REMOTELY SENSED DATA AND IMAGERY IN THE COASTAL ZONE: SOME CONSIDERATIONS AND GUIDELINES

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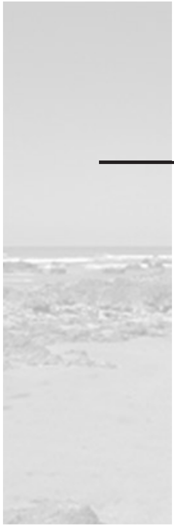
Printed in the United States
ISBN #: --



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Abstract: *This publication seeks to stimulate the interest of a growing number of potential end-users of remotely sensed data and imagery to make greater use of available geospatial data and information processing technology in coastal applications. This publication will help the user become better informed about the application of this technology to coastal environments as well as provide knowledge and understanding about the advantages and disadvantages of the technology. Through careful consideration of the environmental problem, the issues, the data sources, the potential approach, and the expertise required to provide an answer to a question or a solution to a problem, it is more likely that the end-user will make better operational use of remotely sensed data and associated technologies in the workplace.*

This guide is designed to provide introductory insight into the potential role and use of remote sensing in environmental applications with specific reference to coastal areas. It is intended to provide signposts only rather than being an all-encompassing text, and the reader is directed to additional publications and Web-based sources for more information.

Introduction

Remotely sensed data and imagery have been widely applied over the years to coastal environments with varying degrees of success, largely dependent upon the application. Aerial photography, in particular, emerges as a major source of information that has considerable appeal for many coastal applications, primarily because of a user-requirement and desire for “high” spatial detail and visual familiarity and because of the relative ease with which the imagery can be used. The low cost of aerial photography for many local-based studies is also an important consideration. Relatively poor spatial resolution of most satellite data and imagery has, until recently, also meant that they have not become as widely used as was initially expected, despite the considerable advantages offered by greater spectral and temporal resolution and area coverage. With time, the spatial resolution of satellite imagery has improved considerably and this has greatly increased its potential for more widespread use.

Airborne sensors (e.g., RADAR, LIDAR, and CASI) are now also providing relatively high spatial and spectral resolution data and imagery as complementary alternatives to aerial photography and satellite imagery. Although airborne sensors have a huge potential to many environmental agencies and consultancies for monitoring and mapping tasks, they do not yet offer ideal sources, since overflights of coastal areas are not usually undertaken on a regular basis. The data and imagery acquired also require considerable processing and interpretation expertise for both visual and digital image analysis and information extraction. Furthermore, the imagery is not “visually familiar” to many end-users who require information for decision-making and planning in the workplace.

Although remote sensing has the potential to provide valuable and important data and information, it is not always clear for the end-user which sensor will provide the best data and imagery (in terms of spatial, spectral, and temporal resolution) for a particular task or problem. There is, therefore, a need for guidance to assist the coastal scientist, manager, and practitioner in deciding what data or imagery and which sensor will best provide the information required to solve a specific problem. In practice, the coastal task or issue must be carefully matched with the utility (or characteristics) of the sensor(s) and the resulting data and imagery available.

In reality, many problems still exist when trying to utilise remotely sensed technology in the environmental monitoring and management arena. These include a general lack of knowledge and information about the types of data and imagery available and what they can be used for, the techniques available to extract the required information, and a general reluctance to embrace the increasingly integrated sources of information technology designed to aid the user in the workplace.

With greater awareness of the potential of remotely sensed data and imagery by more users, it is important that the potential of remotely sensed data and imagery in the workplace be more widely recognised and promoted. Knowledge of remotely sensed data and imagery can result in placing a greater value on all sources of data and imagery available (either separately or together), it can foster greater appreciation and understanding of the characteristics of all sources of data and imagery in the context of a proposed application, it can foster the use of greater understanding of the techniques of information extraction available including up-to-date information technology (e.g., the Internet and data visualisation tools), and it can provide access to expert guidance for the end-user community about how to make the correct or best choice of data analysis and processing techniques for analysing and interpreting remotely sensed data and imagery.

Remote Sensing

There are many techniques and instruments available for environmental data collection to enable us to observe, record, monitor, map, and ultimately analyse our environment at a wide variety of different spatial and temporal scales (large, medium, and small). Among all of these, however, remote sensing is perhaps the most unique, distinct, and potentially advantageous, with many significant and important opportunities for the environmental scientist and manager, both for research purposes and in the workplace.

Remotely sensed data and imagery have been widely investigated and applied to numerous environments, including coastal. To date, and largely out of necessity, much of this work has been theoretical and experimental, often designed to help develop new techniques that: (a) "sell" remote sensing to the environmental applications specialist, (b) seek to demonstrate the wider applicability of the technology to one or more specific areas, and (c) further our capability to extract geospatial information from the data and the imagery. Although it is recognised that experimental research is an important part of the evolution of remote sensing technology and theory, in recent years, greater emphasis has been placed on making this technology more operational in the workplace for routine day-to-day applications.

Over time, some of the methodologies developed for applying remote sensing technology to our environment (land, water, and atmosphere) have indeed become almost routine and "operational." In many other areas of application, however, remote sensing has been far less immediately successful, sometimes leaving environmental scientists and managers sceptical about the value and advantage of remote sensing technology as a data collection tool over other more traditional methods. In part, this has been due to the fact that remote sensing was perhaps a little "oversold" too soon. However, perception of a general lack of successful applications is often a function of not understanding the technology in terms of the spatial, spectral, and temporal resolution of data, its role as a complementary and integrated data source, the need for processing and interpretation expertise to transform the data into usable information, and an appreciation of when, where, and how remote sensing data and imagery can be of help and when it can not.

Remotely sensed data and imagery of the earth is but one source of geospatial data that can be used to provide information about the environment and the processes at work, and can therefore be used to aid in environmental monitoring, mapping, and subsequently management. Over the past 30 years, the number of different sensors has grown considerably and this proliferation has led to a vast store or archive of multi-spectral, multi-spatial, and multi-temporal data of different scales that is "theoretically" available for use. Such a large database is a unique resource for the environmental scientist because real-world processes operate at a range of different scales and, hence, all the differently specified remotely sensed data will have their own particular uses. Despite this, the vast array of data now available has arguably limited the practical use of remote sensing in the management arena, largely because the end-user, who is usually and increasingly not a remote sensing or geospatial data handling specialist, does not know what data source will aid in the problems that they wish to solve and when, where, and how best to use them.

The coastal zone is an example of a unique and dynamic environment, the effective management of which requires information and a thorough understanding of how it works. For the coastal scientist or the coastal zone manager, geospatial data and information covering a range of different scales and time periods are a necessity.

Why Remote Sensing?

The main reason for considering the role of remote sensing in the context of coastal zones is as a source of up-to-date environmental data and information that assists in the following:

- detection
- assessment
- interpretation
- definition
- evaluation
- depth estimation
- verification
- analysis
- change detection
- impact studies
- data collection
- spatial characteristics
- temporal variability
- emergency response
- information system
- management
- modelling
- information extraction
- visualisation
- planning and response
- decision support

The choice of available data sources and the expertise and techniques required for extracting information will potentially become even more bewildering for the average end-user of remotely sensed data and imagery in the near future. This is all the more reason to provide the end-user community with help and direction in order to make the best use of this "added choice."

Identifying the Problems and Issues

It is necessary at the outset to examine and perhaps question the need to use remotely sensed data and information and the associated geospatial technologies (e.g., GIS) as the basis to investigate an environmental problem.

One should therefore begin by asking a series of questions that provide the contextual setting to proceed. Below is an outline set of some questions designed to help the coastal manager or practitioner determine the suitability of remotely sensed data for a problem, understand the characteristics of the sensor and data to match the data available to the task or issue, and identify which approaches/methods might be appropriate and whether these should be "simple" or "complex." Table 1 lists some key questions to ask.

Once answers to some or all of the questions in Table 1 have been obtained, additional questions need to be addressed. These include:

- What type of data processing and analysis is needed?
- Is visual analysis and interpretation of the imagery sufficient?
- Is digital image processing required?
- What software would suffice?
- What level of expertise is needed?
- Is this expertise available?

TABLE 1: Key Questions Regarding Remotely Sensed Data

- What is the exact problem?
- Is the problem real-time?
- Where exactly is the problem?
- What is the scale of the problem?
- Is the problem spatial and temporal?
- What spatial data and information, or imagery, are potentially needed to address the problem defined? (ideal)
- Is multi-temporal spatial data and information or imagery needed?
- What are the ideal time intervals between spatial datasets/imagery?
- What spatial data and imagery are available?
- What are the characteristics of these data/imagery?
- What is the scale of the spatial data/imagery?
- What metadata (or documentation) is available for the data/imagery?
- Do the data/imagery available match the criteria for its use?
- Can the data/imagery be used and in what capacity?
- What is the availability of the data/imagery?
- What is the cost of the data/imagery?
- Are new data/imagery required?
- What pre-processing/conversion is needed?
- What technology (hardware and software) is needed?
- What technology (hardware and software) is available?
- What is the cost of the hardware and software needed?
- What expertise is needed?
- What expertise is available?

The outcome of this series of questions is to focus attention directly on the exact nature of the problem, the data/imagery available and needed, and the approach or method to be used that will result in an answer or solution. This requires the end-user to provide a suitably detailed background to the problem in terms of either the issue or problem being addressed and the data available.

The end-user not only needs detailed knowledge of the sensors and imagery characteristics, but also the digital image processing (DIP) techniques, the effect the data processing and analysis will have on the raw data (that may result in a new image), and how to interpret the end-results. Moreover, in order to help the end-user make sense of the imagery, there must be an understanding of the "cause-effect" relationships between the ground and the sensor record. Knowing how a surface or feature interacts with different portions of the electromagnetic spectrum and how much energy is returned to the sensor is very important when trying to extract information from the recorded signal. While it is often difficult to know exactly what the ground surface/feature status is like at the time a sensor passes overhead, a general knowledge of the spectral reflectance and emittance characteristics of each of the surfaces helps to provide enough information to make more sense of the image record.

In practical terms, the next consideration is to determine what can be done with the archival or new data/imagery that is available. In many cases the data available in practice, say for coastal zone management, may not be ideal; that is, it may not have been specifically collected for the task. This means that it may not be at the right scale, cover the entire study area, be free of cloud cover, include the right spectral bands, be multi-temporal, or geo-corrected. In other words, there may be a number of problems that require attention and solution before attempting to use the data and imagery; this is in addition to other considerations such as the cost of the data and the question of ownership and copyright.

In general, unless funds have been made available to provide for custom datasets for a project, it is more than likely that the datasets will be archival or legacy. If this is the case, some consideration will need to be given to the extent of analysis that can realistically be undertaken.

In some cases, the fact that available datasets are at different scales may mean that the data needs to be resampled in order to be able to undertake an overlay analysis. However, it may not be possible to do this without introducing an element of error into the "equation."

Ideally, the datasets available to the end-user for a particular task will have been collected for the purpose, where the objectives and methodology of the work have been carefully thought through. More often than not, however, it is likely that the potential datasets will come from many disparate sources. While at first glance they may seem to be of use, in practice they may not be of use in an analysis, as they lack metadata. If this is the case, serious consideration must be given to the objectives of the entire exercise, and, if some of the datasets are of unknown origin, some changes or adjustments to the proposed methodology may need to be considered.

Key Issues: Choosing Imagery from the Right Sensor

The Literature

Examining the remote sensing and other related literature provides a good indication of some of the applications that have been undertaken to date, the findings, and the conclusions, all of which can provide a useful and often frank indication of the suitability of the different types of data and imagery for different applications A thorough literature search can therefore be a very useful starting point.

Where to Next?

Assuming that an improved familiarity with the application of remote sensing to coastal applications has been carried out, how can the better-informed potential end-user make use of remote sensing for a new application in a new study area?

Some Guidelines

Existing Approaches

Providing guidelines for the use of remotely sensed imagery has become a topic of increasing interest in recent years. It is notable, for example, that a book titled Aerial Imagery Guidelines (Deck and Tsui 1999) was recently produced on aerial photography. A number of conference workshop sessions have also set out to tackle the problem of how to choose the right dataset for the task. For example:

- Multisensor Approach to Mapping and Monitoring Coastal Habitats in South Carolina: Selection of the Appropriate Data Set (Workshop). (Althausen and Grossa 2000).
- Archiving Aerial Photography and Remote Sensing Data: A Guide to Good Practice (Bewley et al. 1998; http://ads.ahds.ac.uk/project/goodguides/apandrs/).
- Transforming Remote Sensing Data into Information and Applications (Space Studies Board 2001).

A Framework Approach

Phinn et al. (1999) devised an approach titled "Optimising Remotely Sensed Solutions for Monitoring, Modelling, and Managing Coastal Environments." The justification for such an approach relates to:

- an increase in the number of remotely sensed products now available and likely to become available in the future,
- an increase in the number of end-users of remotely sensed imagery, and
- the growth in integrated approaches to geospatial data handling typically within a geographic information system (GIS).

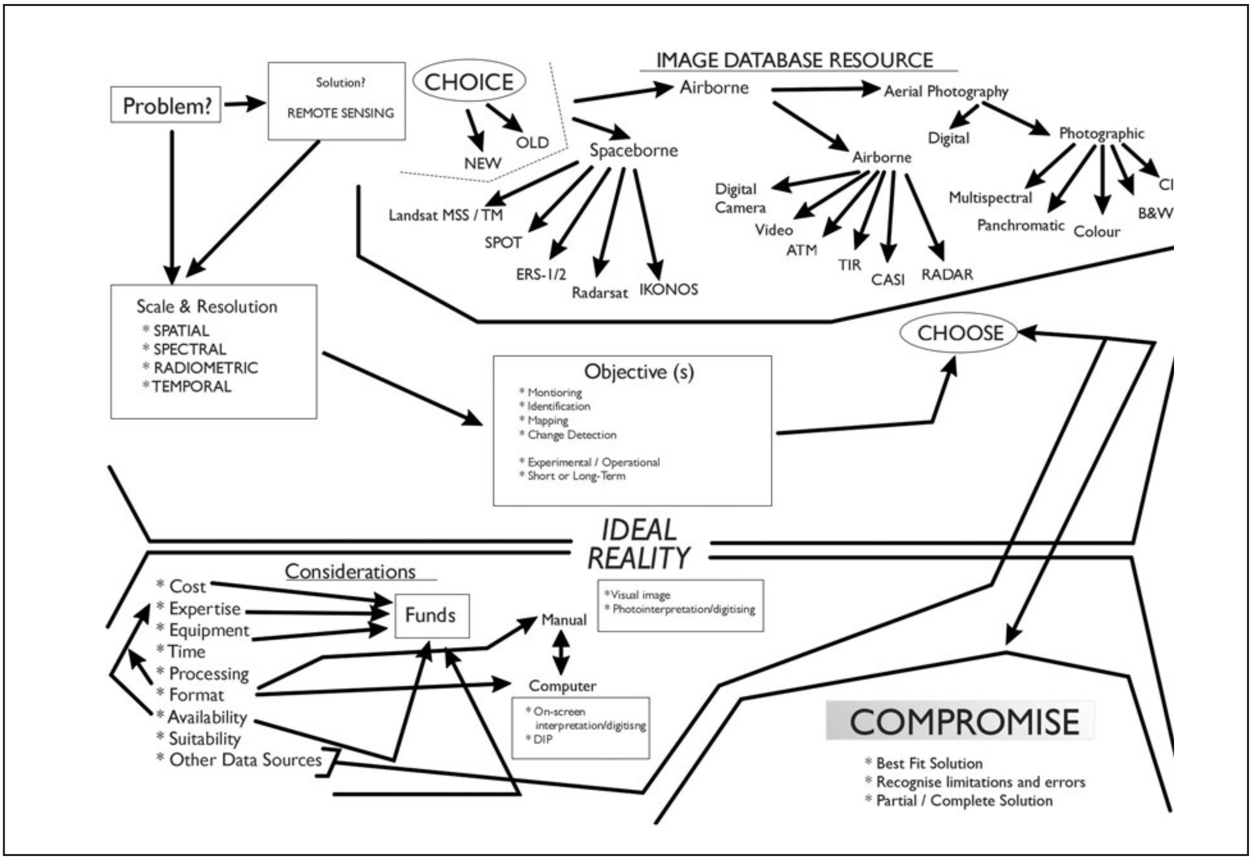


Figure 1. Choosing remotely sensed imagery

Examples of Practical Scenarios

The above framework, while a valuable and objective approach, has some practical drawbacks for the end-user, in that the spatial and spectral analyses proposed as an essential component of the chosen procedure are complicated and rely upon possessing a detailed knowledge of remote sensing. In some ways, this is inevitable as the technology is itself complex. However, there is perhaps also a need for a more basic set of guidelines for the practical and potentially one-off use of remotely sensed imagery that may necessitate only a simple approach to choosing and handling remotely sensed imagery for coastal studies. Tackling the problem of how to proceed with the decision to use remotely sensed imagery can be based upon considerations shown in Figure 1.

In practice, the choice lies between the ideal and reality; in other words, the constraints facing the end-user. For example, knowing what remotely sensed data and imagery are available and the characteristics, the problem, matching the imagery to the problem (such as spatial detail or spectral properties), and deciding whether or not it can be used.

In reality, there are a number of scenarios that need to be considered as example situations. All of these scenarios assume little or no remote sensing or GIS expertise.

Scenario 1: Limited Expertise, Funding, and Available Equipment

Setting. Remotely sensed imagery is considered to be useful. As the potential end-user, you have done some background reading and, based upon a sound knowledge of your particular problem, you have a strong feeling that an airborne or spaceborne perspective could be useful to help address the problem or task that you have identified. However, you have limited funds and little or no expertise or hardware/software for processing remotely sensed imagery or geospatial data. How do you proceed?

Solution. Some questions that must be asked are:

- What do you require the data/imagery for (reconnaissance, monitoring, mapping, change detection, etc.)?
- How big is your study area?
- What spatial detail do you require?
- Do you require quantitative measurements?
- Are you planning to do any analysis?
- Are you looking for spatial patterns?
- Is it archival or current data/imagery that you require?
- Do you require more than one date of data/imagery?
- Is this a one-off exercise or likely to be repeated?
- Where is the data/imagery held?
- Can you use it?
- Is simple visual analysis adequate for your task?

If you are planning to study a relatively small ground area, then you will likely need airborne imagery of some sort. If it is detail (large scale) you are seeking, you have a number of choices, which will largely be dependent upon the smallest feature you need to resolve – for mapping purposes, the minimum mappable unit.

In most cases, aerial photography (panchromatic or colour) is likely to be the most obvious choice as it has comparatively high spatial resolution, is relatively low-cost, provides a familiar visual image, can be easily located, is well-documented in the published literature with plenty of examples of interpretations, photointerpretation keys etc., to use as templates, and is, with or without knowledge of photointerpretation and equipment, relatively easy to use for visual interpretation and basic mapping tasks. Using the factors described in Table 5 in the section on photointerpretation, plastic overlays, and pens, this can be achieved relatively easily. If available, a pocket or mirror stereoscope can also be used.

Multi-spectral aerial photography and colour infrared imagery are useful and easy to use, but generally require more background knowledge about the spectral reflectance of surfaces and the resulting image record to make use of it. It is also unlikely to be generally available. Despite being unfamiliar to the eye, the visual image is nevertheless relatively easy to interpret with some practice, usually because of the spatial detail and the correspondence to what can be seen on other sources of information (e.g., a map or from field work at ground level). Inevitably, a natural approach to interpreting any remotely sensed imagery will be to refer to other sources of information.

In some cases, multi-temporal photographs may be available (although usually not for the times of year and for the years ideally required) and this can be used for comparisons, for example, to aid in the interpretation of a single date of imagery, or used for simple change detection studies. In general, the use of multi-temporal photography requires more experience and knowledge of the spectral reflectance characteristics of different surfaces, that may also change markedly over time due to transient effects such as cloud shadow; similarities between different surfaces at one or more points in time that will prevent the interpreter from drawing a conclusion about its identity.

For many monitoring and mapping purposes, the simple approach to image interpretation, specifically using aerial photography (35-mm hand-held, 70-mm vertical, oblique and standard aerial format), is perfectly adequate and with a little practice can be used to provide the information required. Ideally, the more recent the photography, the larger the scale and the more useful it will be.

If funds are available to purchase hard copy of other types of remotely sensed data/imagery (e.g., airborne (RADAR, LIDAR, or CASI) or satellite (e.g., Landsat or SPOT)), then this too can be interpreted visually and the information mapped onto tracing paper or a transparency with a pencil or pen. Much, of course, depends upon what information and level of detail is being sought and what can ultimately be seen on the imagery. For satellite imagery, the spatial and spectral resolution, scales, and coverage mean that spatial patterns (rather than fine detail) can be more easily seen and mapped, etc.

Limitations. In the case of aerial photography, interpretation without a stereoscope and even photogrammetric equipment (e.g., a Zoom Transfer Scope) means that its use is necessarily limited. The three-dimensional stereoscopic image provides a more realistic and informative source than a single photograph viewed unaided or even with a magnifying glass. It will also not be possible to create a planimetric or near planimetrically correct map from the information derived from the imagery unless the ground terrain being studied is relatively flat. This limits the possibility to derive accurate linear and area quantitative measurements from the photography, which may be important in, for example, change detection studies - knowing not only what area has changed from Time 1 to Time 2, but by how much.

The choice of the source of imagery will also be important for successful results. The best aerial photography will obviously come from professional aerial survey companies using high quality cameras, films, and lenses.

Generally, the more recent the photography, the better the quality. Archival photography is often not clear to look at, appearing slightly fuzzy or hazy, and may lack contrast and resolution, and the coverage is often variable for large-area studies. Aerial photographs from model aircraft, helicopters, kites, balloons, and rockets will be susceptible to considerable spatial distortion, and without correction will have limited use, being confined mainly to simple visual photointerpretation, which involves the identification of features and perhaps simple linear and areal measurements based upon comparison with maps of known scale. This may, however, be all that is necessary.

Scenario 2: Limited Funding, But Some Computer-Based Equipment and Expertise

Setting. Remotely sensed imagery is considered to be useful. As the potential end-user, you have done some background reading and, based upon a sound knowledge of your particular problem, you have a strong feeling that an airborne or spaceborne perspective could be useful. However, you have limited funds and limited expertise or hardware/software for processing the imagery. How do you proceed?

Solution. The availability of a computer together with hardware peripherals such as a scanner and some basic DIP or GIS software will provide an opportunity to convert any analog imagery available (e.g., archival aerial photography) into a digital format and to process it using DIP software. There are a number of advantages over Scenario 1:

- There is the possibility to do simple on-screen interpretation and digitising or mapping.
- Image frames can be stitched or mosaiced together.
- The images can be geometrically corrected.
- Quantitative measurements (e.g., distance and area) can be derived.
- Simple image processing techniques can be applied to help enhance the imagery for visual interpretation.
- Image data can be integrated with other geospatial datasets. The computer-compatible format also offers numerous advantages in

the form of being able to provide long-term storage of the imagery and to experiment with various image-processing techniques.

While the availability and use of computer hardware and software is not a panacea for the successful extraction of information from remotely sensed imagery, it nevertheless offers a number of distinct advantages over traditional approaches, some of which can aid visual interpretation (by highlighting features through "colouring in" and increasing visual contrast), comparison, the derivation of quantitative data and information, monitoring and mapping, and the long-term use and re-use of the imagery.

Limitations. Some consideration must be given to the conversion of analog imagery into a digital format. In all likelihood, the information content of the original will be degraded somewhat by scanning, and knowledge of the effects of the selected scanning resolution will be required. Digital image files are also usually large to store and process.

A detailed knowledge of the likely effects of certain image processing techniques must also be held by the end-user, since the processing of one image into another will be the basis for any subsequent visual interpretation. Transformation of a visually familiar image into one that is unfamiliar, for example, pseudo-colour, may ultimately hinder the visual interpretation process without recourse to other support materials (i.e., ancillary or contextual data and information).

Scenario 3: Available Funding and Some Limited Computing and Remote Sensing Expertise

Setting. The availability of funding provides some opportunity to acquire data/imagery and a range of both traditional and computer-based equipment to aid in the interpretation or information extraction. The question to be asked is this: Because you have available funding, is new imagery and equipment absolutely necessary? The answer to this will depend upon the objectives of the project. In all likelihood, new imagery is likely to be highly appropriate to a study. This may take the form of a new set of images acquired from a known source or, if possible, the commissioning of new imagery for the project. In the latter case, it will be necessary to consult with an expert to ensure that the money is well spent on data/imagery suitable for the purpose and that it is of an appropriate scale and resolution, whether airborne or spaceborne. Much imagery is now already in a digital format, which means that it can be input directly into a computer and the imagery analysed by simple on-screen display, the use of DIP techniques, or simply the use of visual interpretation of the image as hard copy. The choice will largely depend on the expertise available and the time and cost of the exercise.

Funding also provides the opportunity to purchase a range of imagery from different sources, equipment, and expertise. The latter may be appropriate in order to process the imagery purchased, both from the standpoint of expert knowledge as well as the opportunities provided by the use of new technology to turn the data into information. Again, this will depend upon the project and what is to be undertaken. However, computer equipment should only be purchased if it can be justified.

Should airborne and spaceborne imagery be acquired, then the choice of DIP techniques will depend upon the objectives of the exercise. If you simply wish to enhance the image, with the aim of extracting spatial patterns and information visually, on screen, then techniques such as density slicing, filtering, and contrast stretching may be sufficient. These are relatively elementary techniques and can be selected from the DIP software menus. The advantages of using software are that multiple images can be compared and contrasted using separate window displays, as can the effects of the image processing techniques on the original image, providing an opportunity to determine whether a particular approach enhances detail/contrast or suppresses it. To a large extent, the application of image-processing techniques also provides an opportunity to experiment with a range of tools and techniques designed to aid in the extraction of spatial detail (e.g., orientation of features, boundaries between features, the shape of features through contrast enhancement, and spatial pattern through the identification of homogeneous units).

If further information extraction is required, it may be necessary to explore more sophisticated techniques, for example, vegetation indices such as the Normalised Difference Vegetation Index, Principal Components Analysis, Intensity Hue Saturation transforms, and supervised and unsupervised classification and hybrid approaches. Some of these techniques, such as vegetation indices, have a specific outcome (e.g., they emphasise vegetation biomass) and there are a number of well-documented examples in the literature for reference.

Limitations. A fairly large budget is required for purchasing multiple sources of multi-temporal imagery, as it is for hardware and software sufficient to handle a large quantity of data and imagery. To this must be added costs to cover expertise and time, as well as fieldwork. Image processing requires the user to have a fair amount of expertise with computers and applications to undertake all the different stages from data input/import, storage, preparation, and analysis to output of, for example, a map. Perhaps the most difficult part is interpreting the outcome of an analysis. In essence, funding may offer the possibility to use more varied sources of imagery; however, the use of digital data requires expertise, equipment, and time and offers some advantages of information extraction, but the use may ultimately depend upon the end-user's ability to visually interpret either one or more raw or transformed images.

Radiometry, Ground Truthing, Cause-Effect Studies, and Modelling

Radiometry, Cause-Effect Studies, and Modelling

Radiometric "cause and effect" studies (of which much well documented theoretical and modelling literature is now available) are a very important part of our resource to assist in the interpretation of data and imagery or to extract information (either manually or using semi-automated techniques).

The literature can be divided into three distinct areas of study:

1. Spectral radiometric studies designed to collect reflectance and emittance data at the ground level as the basis for creating spectral databanks and documentation of spectral reflectance from different surfaces (in the form of spectral reflectance curves spanning the visible and near infrared portion of the electromagnetic spectrum), which act as reference materials.
2. Data collection designed to validate spectral reflectance and emittance models.
3. The development of radiation theory and mathematical models of emittance and reflectance from different natural and man-made surfaces.

Theoretical and experimental work has sought to characterise different surfaces in terms of their spectral reflectance and emittance properties, as well as to make use of surface reflectance and emittance models, providing greater knowledge and understanding of how solar radiation interacts with different surfaces. In essence, such knowledge, understanding, and resources play a crucial role in aiding in extraction of information from remotely sensed imagery, especially in cases where ground truth data and information may not be available.

Ground Truthing

While much analysis and interpretation of remotely sensed data and imagery are undertaken in a laboratory using either photointerpretation or DIP techniques, it is likely that any remote sensing exercise will require ground checking or truthing to be carried out. Typically, ground truthing refers to the landward side of the coastline, while sea truthing is the appropriate term applied to the seaward side. Ground or sea truthing involves a comparison of the imagery interpretation to the "real world" and is deemed necessary to validate the interpretation. The real world usually means fieldwork visits to sites on the ground or may simply utilise other sources of spatial data and information, including 35-mm ground photographs, text, personal contact, and maps.

The usual approach is to use a representative sample of points or to select locations where there has been particular difficulty in the interpretation process. This involves selecting areas that prove difficult to identify or classify (e.g., where spectral confusion between desired categories occurs). Calculation of the classification accuracy or error of an interpretation is often used to estimate how good the classification is. The resulting confusion matrix reveals which pixels were accurately classified, which were errors of commission (pixel assigned to a class to which it does not belong), and which are errors of omission (pixel not assigned to its appropriate class).

Careful Choice and Data Integration - The Key to Using Remotely Sensed Data and Imagery

The key to effectively using any remotely sensed data and imagery for a particular application is to have an "in-depth" appreciation of the problem or issue. The next stage is to identify which data and imagery may help to solve these issues.

Ultimately, the information extracted from the data or imagery will depend very much upon a visual interpretation. The overall goal is to maximise the extraction of the information you are seeking from the data or image source using traditional visual techniques or computer-based processing, enhancement, and display.

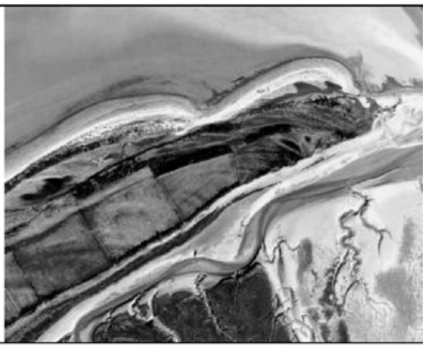
There are many products from many sensors now available (Figure 2). They provide a wide range of spectral, spatial, and temporal resolutions, have a distinct role to play in environmental data acquisition, provide roles that are often complementary, and often require integration to be successful.

Spatial Vs. Spectral Resolution: Aerial Photography, Airborne and Satellite Imagery

If remotely sensed data are chosen for an application, then in nearly every case the primary perceived end-user requirement is to acquire the best spatial resolution possible. While one or more sensors may deliver the required level of spatial detail, often it is at the expense of spectral resolution or the problems associated with interference in the sensed/recorded signal caused by atmospheric attenuation. Although spatial resolution is not always vital to address a particular type of problem, many end-users almost automatically consider "detail" as the most important requirement to justify the use of remotely sensed data and imagery for an application.

Aerial Photography

Aerial photography is the most common form of remote sensing that has been and still is widely applied worldwide. The literature reveals aerial photography to be one of the most widespread sources of remotely sensed data, whether panchromatic, near infrared, multi-pectral, colour, or colour infrared/false colour. For many years, aerial photography has "ruled supreme" in the array of remote sensing available for use. Its many advantages include known history, widespread availability, cost-effectiveness, relative ease of interpretability, and spatial resolution, the "all-in" combination has remained largely unchallenged until recently with the arrival of new airborne and spaceborne products.



Colour aerial photograph
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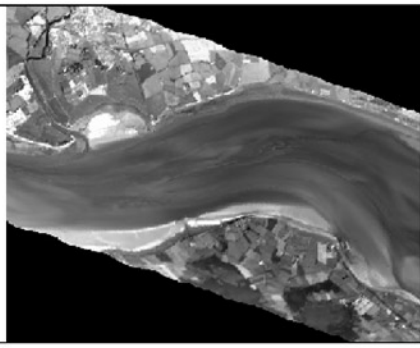
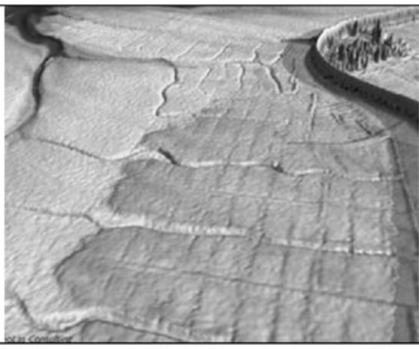


Compact Airborne Spectrographic Imager (CASI)
© Environment Agency NCEDS (1994)



Light Detection and Ranging (LiDAR)
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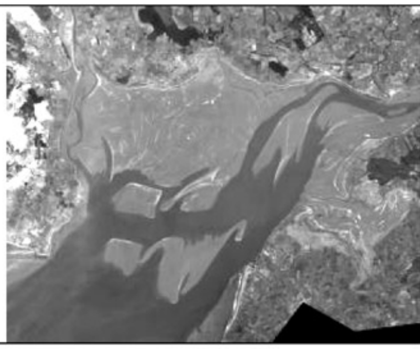
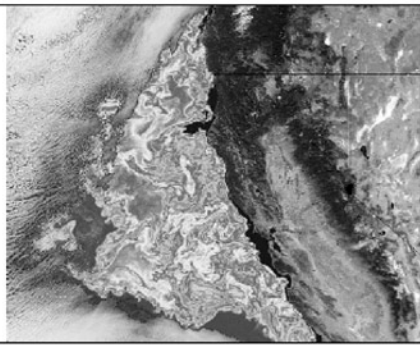


Système Pour l'Observation de al Terre (SPOT)
© CNES (1994), reproduced by David R. Green & Stephen D. King under licence from SPOT IMAGE

Landsat Thematic Mapper (Landsat TM)
LANDSAT data ♥ NOAA. Distributed by CHEST under license from Infoterra International



Sea-viewing Wide-Field-of-View Sensor (SeaWIFS)
NASA Goddard Space Flight Center
http://seawifs.gsfc.nasa.gov/SEAWIFS.html

Figure 2. Examples of some remotely sensed imagery used in coastal applications

Aerial photography has been successfully used for many coastal applications and still is, on a repetitive basis, either using a single image or stereopairs, depending upon the objectives and requirements of the application. The techniques of aerial photointerpretation and photogrammetry are well developed. Aerial photographs are widely used by many people, including some with little training. In recent years, the practical use of aerial photography has been enhanced by the availability of low-cost digital information technology (computing hardware, software, and peripherals such as scanners), GIS, digital cameras, digital image processing, and digital photogrammetry, providing a range of easy-to-use viewing and processing tools for a wider end-user community.

Whatever promise satellite and airborne sensors appear to offer to the end-user, the drawback for many perceived applications requiring "spatial detail" has been the relatively poor spatial resolution of much of the "competing" imagery. Although spatial resolution of other sensors has improved greatly over time, most have not really come close to providing such a simple, well-rounded, and usable solution to match end-user requirements, expertise, and budgets.

However, this may change with the availability of products from Space Imaging's IKONOS satellite series and many of the new space platforms and sensors being proposed and launched, for example, Envisat. However, there are many corresponding new developments in aerial films and digital cameras to consider as well.

In many cases, aerial photography has been the most "convenient" source, with coverage of many parts of the world being available and repeat overflights relatively frequent. Aerial photography is also of relatively low cost for local or "small-area" studies, and ultimately "cost-wise" and "availability-wise" simply "fits the bill" for many end-users. It can be acquired using platforms such as model aircraft, kites and balloons, microlights, and autogyros as well as light aircraft. Other remotely sensed data and imagery have neither the spatial resolution nor are they always available and are, for the purposes of an application in mind, often too expensive. In developing countries, aerial photography is still widely used because it is relatively easy to acquire and to use for many of the tasks where up-to-date data and information are needed. Table 2 lists many of the advantages and disadvantages.

TABLE 2: Advantages and Disadvantages of Aerial Photography

Advantages

- well-supported
- widely used
- large user knowledge base
- requires little expertise to use
- simple technology
- archival value
- visually easy to interpret
- continually evolving through new developments
- high resolution
- easy to make print copies
- 3D interpretation easier
- films and black-and-white prints store easily

Disadvantages

- spectral resolution is poor and the entire spectral range is often contained in a single image
- digitising is time consuming
- success can be determined only after development (changing with digital cameras)
- difficult to add other information during imaging
- picture cost is high

Aerial photography also suffers from various distortions, which may affect its use unless taken into account (Adams 1996:698):

- lens
- shrinkage/expansion of the paper print
- tilt displacement
- relief displacement
- scale differences

These can affect the application if, for example, quantitative measurements are required and must therefore be carefully considered. Scanning aerial photographs for use in an electronic environment can also introduce sources of error affecting the subsequent use of the imagery.

Choice of colour or black-and-white photography will depend upon the intended use. Panchromatic aerial photography is, for example, often considered better for survey work (e.g., mapping features by drawing boundaries around identifiable "units") and where the colour of ground features is not deemed important. Colour photography is, however, more useful in a study when identifying the content of map features or units (Jones 1996a, b:15-17).

Airborne Sensors

Airborne sensors such as the United Kingdom's Airborne Thematic Mapper (ATM), Thermal Infrared (TIR), RADAR (Radio Detection and Ranging), Compact Airborne Spectrographic Imager (CASI), and Light Induced Detection and Ranging (LIDAR) have recently proved to be attractive alternatives to both aerial photography and satellite imagery. They have provided new opportunities to capture high-resolution imagery, reduce acquisition costs for small area coverage, allow for end-user specification of the right imagery for the task, and extended acquisition to cloud-penetrating data and imagery (e.g., RADAR). Increasingly, they have also found appeal for some coastal applications because they offer the closest spatial resolution to aerial photography and improved spectral resolution, which makes them comparable to satellite sensors, and all-weather capability (e.g., RADAR).

Where the coverage of a small geographic area and the mapping of ground features smaller than 1 square meter are required, aerial photography is probably still regarded as being the most cost-effective and easy-to-use image data source currently available. For large area coverage, satellites are still seen as the most cost-effective, even though few offer the spatial detail often required. In terms of geographic coverage and spatial resolution, airborne sensors fall somewhere in-between and, depending on the application, may or may not be as cost-effective. However, the requirement for spatial detail must also be set against other needs and priorities. See Table 3 for the advantages and disadvantages of using airborne sensors.

Thermal Infrared. Thermal infrared line scanner data and imagery are also potentially useful as they provide unique sources of data and information (e.g., thermal plume detection). Advantages are the daytime/nighttime capability as well as all-weather penetration. Once again, availability is the limiting factor for the end-user, as well as the difficulty posed when interpreting the imagery which, although initially similar in appearance to a panchromatic aerial photograph (because it is often available in a photographic print format), is much more difficult to interpret because of the unfamiliar grey tones of the photographic end-product.

Digital image processing (e.g., density slicing) can be used to visually enhance the imagery and assist in the ease of interpretation by revealing, for example, spatial patterns. Ideally, ground truth and calibration data are required in order to help interpret the tones or signatures on the imagery (e.g., to identify features that are relatively cool or warm).

Compact Airborne Spectrographic Imager. CASI is increasingly one of the most favoured images, being useful for mapping, for example, in coastal waters. It

TABLE 3: Advantages and Disadvantages of Airborne Sensors

Advantages

- Selectable spatial resolution to match the scale of features of interest
- Selectable time of data acquisition during a day or through the year, to use weather windows, to match critical stages through a season or in response to special events
- Repeatability for multi-flight missions (e.g., throughout a single tidal cycle)
- Potential to fly in different flight directions to enhance diagnostic features or minimise unwanted contributions
- Potential for sensor test beds and availability of "state-of-the-art" sensors (i.e., imaging spectrometers that are not yet available in orbit)
- Potential for re-calibration of sensors under laboratory conditions

Disadvantages

- Lower spatial coverage, limited to local and regional scales only, and requiring multiple flight lines
- Limited range of operations due to aircraft speed/ endurance
- More complex geometric rectification due to turbulence at airborne altitudes. A problem of increasing importance with the growing use of a geographical information system to analyse other georeferenced datasets
- More complex atmospheric correction due to flying at sub-orbital altitudes and by sensors with much wider field-of-views

provides high spectral resolution and variable spatial resolution data/imagery, which are highly suitable for many coastal applications. Spatial resolution is dependent upon the flying altitude of the sensor platform (e.g., 2-4 and 10 m). The main benefit of CASI imagery is its multi-pectral resolution (12 to 16 or more channels). CASI is also considered to be as cost-effective as other sources of imagery such as aerial photography (Mumby et al. 1998).

Light Detection and Ranging. LIDAR is currently being widely promoted and used as a sensor to provide data and imagery for the derivation of digital terrain or digital elevation models as well as its value for calibration purposes. LIDAR can also provide hydrographic and topographic data "in one" (McClung 1999).

Airborne Video. Although the application of airborne videography has had relatively limited success to date because of spectral and spatial limitations, image quality has recently improved. It is often designated "near-real-time" imagery. The imagery can be manually interpreted or subjected to digital image processing, offering possibilities for integrating it with other data sources. Still video images may also be acquired from videotapes using computer and video editing software. Specialist software is also being developed to derive stereo video imagery. Video is particularly suitable for monitoring and recording of linear features such as coastlines.

Video has also proved to be an extremely valuable source of reconnaissance imagery, largely to complement other sources (Bobbe et al. 1993:37). It is relatively inexpensive and easy to acquire and can be integrated within a GIS with other georeferenced imagery and data. Video is a flexible sensor regarding deployment in less than ideal weather conditions. Although not useful for large-area coverage and where high spatial resolution is needed, it can complement other remote sensing and map data for environmental monitoring. There is growing interest being

TABLE 4: Advantages and Disadvantages of Video Imagery

Advantages

- higher light sensitivity and wider spectral response
- images can be viewed in real-time
- aircraft dynamics can be used to recover image geometry
- interpretation of images on a television monitor
- video signal is readily digitised
- success is determined in real time
- can add other information (verbal) in real time
- picture cost is low

Disadvantages

- weak and relatively low spatial resolution
- picture motion necessitates a shuttered camera when imaging scale is large
- 3D interpretation requires special equipment
- storage of tapes is uncertain
- relatively long exposure time of 1/60 seconds limits operating conditions

shown in video imagery because of the availability of lower cost cameras. Small video camera systems have even been successfully mounted on light aircraft and remotely controlled aircraft for low-cost image acquisition for coastal monitoring projects.

Table 4 lists several advantages and disadvantages of using video imagery.

Airborne and Spaceborne RADAR: All-Weather Capability. Cloud cover and fog often place a serious constraint on the use of other types of remote sensors in coastal environments. RADAR data and imagery have been available for some time in the form of SLAR (Side-Looking Airborne Radar) and SAR (Synthetic Aperture Radar). The popularity of RADAR sensors, on both airborne and spaceborne platforms, has grown rapidly as the technology has improved and become an alternative source of information for some applications around the world. With improvements in technology and the popularity of satellite data and imagery, airborne SAR has become more important than in the past as a source of information. However, it is not usually widely available and is often only acquired for special projects.

RADAR has undergone considerable development in the last 10 years, and many space platforms now also carry radar sensors. The best known of these are ERS-1 and ERS-2, and RADARSAT. Improvements in spatial resolution, coupled with the other known advantages of all-weather use and daytime/nighttime capability, have made these important and unique sources of data and imagery. SAR sensors have also been carried on-board JERS-1 (Japanese Earth Resources Satellite). While ERS-1 and 2 and NASA's (National Aeronautics and Space Administration) SIR-C are well-known radar sensors, it is the Canadian satellite RADARSAT that has found increasing use around the world, being aptly described as an "operational sensor." Advantages such as user-selectable beam modes have made it possible to choose the radar product delivered to the end-user, thereby widening its appeal. Development in this direction is growing more common as increasing consideration is now being given to the end-user community and matching their requirements (e.g., spatial and spectral resolution to the data and imagery acquired).

Developments in radar interferometry have also been successful for the creation of Digital Elevation Models and Stereo Intersection. However, while the advantages of cloud penetration are important, there is also a trade-off in spatial and spectral resolution that must be taken into account.

Visual interpretation of the imagery, which tends on first glance to look similar to an aerial photograph, is more difficult than might at first be thought since the imagery is frequently not visually familiar to the human eye, although some features (based on shape, pattern, and orientation recognition) can be easily identified. In part, this limitation has restricted its widespread use, often making interpretation, based upon the original signal and the image record, difficult. Indeed, considerable background knowledge of the interaction between the radar pulse and the ground feature (smooth or uneven surface) is required before one can begin to understand the information contained in the data signal or the visual image (e.g., understanding high returns based upon surfaces that act as corner reflectors).

Satellite. In some ways, it is unfair to compare much of the satellite data and imagery with airborne sensors and aerial photography, especially if the end-user lacks knowledge of each of the satellite sensor's spatial, spectral, and temporal resolution characteristics.

Despite their recognised limitations, satellite data and imagery (e.g., Landsat and SPOT) have found increasing popularity because of frequency of coverage, areal extent of coverage, computer compatibility, and timeliness for many applications. The primary advantages of satellite imagery are the digital format of the data, the rapid data acquisition for large areas, the relatively low cost for some studies, global coverage, up-to-date/currency, synoptic view, and because the imagery is multi-temporal, accurate, and flexible. Satellite imagery is also more directly suited to some applications and requirements than others (e.g., those requiring coverage of a large area all at once or the examination of large-area spatial processes).

Nevertheless, while satellite imagery has found numerous applications, more a result of its better spectral rather than its spatial resolution, the level of detail provided has not really matched "public" expectations with regard to proposed applications and it has often offered only very generalised information that is not compatible with investigations.

However, data and imagery from new satellite sensors with medium and high resolutions are now becoming widely available. It is expected that such high-resolution data will compete directly with aerial photography. Customisation of the data will also allow people to utilise the imagery directly in a GIS, ensuring greater integration of datasets from multiple disparate sources. This too will help to make greater use of the remotely sensed data as just one of many sources of data and information for environmental studies.

Fine-resolution sensors are primarily intended for detailed, localised mapping (Barnsley and Hobson 1996:34). Finer spatial resolution also offers the possibility of undertaking better geometric correction and extracting more detailed information. On the other hand, coarse resolution sensors such as ATRS (Along-Track Scanning Radiometer) instruments on ERS-1 and 2 and Polder and GLI (Global Land Imager) instruments on ADEOS-I and II, SPOT-Vegetation, the European Space Agency's Meris (Medium-Resolution Imaging Spectrometer), and NASA's MODIS (Moderate Resolution Imaging Spectroradiometer) together with MISR (Multi-angle Imaging SpectroRadiometer) sensors are more suited to tasks that require larger area coverage.

However, high-resolution spaceborne sensors cannot usually replace film cameras for the following reasons (Baltsavias 2000:38):

- resolution is limited to about 1 m and for the multi-pectral mode to 4 m,
- cost is very high for small areas,
- radiometric quality is generally worse and geometric and radiometric calibration more difficult than with equivalent airborne sensors,
- image acquisition data and time are more restricted than with airborne sensors, and
- image acquisition underneath clouds is impossible.

Landsat MSS, TM, and SPOT. Landsat MSS, TM, and SPOT (Le Systeme Pour 'l Observation de la Terre) have proved the most popular sources of remotely sensed data and imagery to date for many applications. This is largely due to the widespread availability of the imagery and, in some cases, the low costs of archival data and imagery made available to the end-user. Most other sources of satellite imagery have not found such widespread popularity, either because of their general lack of availability, cost, resolution, and timeliness.

Landsat MSS and TM merit consideration for some types of coastal applications where the task is correctly matched to the data available. Indeed, such data sources offer a unique set of multi-temporal data and imagery required by some studies and, in reality, perhaps the only sources that while not perfect, may in fact be useful. For example, spatial detail has been found to be less important than spectral details for mapping coastal salt marsh vegetation (Reid Thomas et al. 1995).

Landsat TM can, with the aid of special DIP techniques, be used to map (e.g., bathymetry in the near-shore environment) by correlating water depth measurements at selected ground control points with variations in the image's spectral signatures (Corbley 1998:37). This is optimised by capturing the data at times when the water column is relatively free of suspended sediments and when there is less wind to make the water turbid; this is not always achievable or repeatable should a methodology be developed.

Coastal Zone Colour Scanner and AVHRR. Uses of the Coastal Zone Colour Scanner (CZCS) to date include:

- calculated plankton productivity on a global scale, tracking regional and seasonal variabilities for input to various carbon cycle and global change models,
- environmental pollution monitoring,
- physical oceanographic features since fronts, eddies, and upwellings can be clearly seen, and
- continuous time series of baseline information on conditions in coastal areas around the world since 1978, which can be used in conjunction with data from SeaWiFS and MODIS.

A detailed resource for the use of CZCS data and imagery is provided by NASA:
(http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/CZCS_Starter_kit.html)
entitled "Getting Started with Coastal Zone Color Scanner Data."

The application of CZCS data and imagery is ultimately limited by the dates of the imagery available due to the satellite sensor's short lifespan. To this end, AVHRR (Advanced Very High Resolution Radiometer) is probably better for some purposes because of the large data archive available.

SeaWiFS. SeaWiFS (Sea-viewing Wide Field-of-View Sensor) has been widely used for sea and ocean studies at large scales (Environ 1999:19). The relatively low spatial resolution of the data means that it is usually used as part of an investigation, making use of other more detailed sources at points that merit further investigation.

Underwater Sensing

Rapid developments have also been made toward the application of high-resolution underwater imaging, mostly in the form of side-scan sonar. Many applications have been undertaken using equipment that provides an image very similar in appearance to an aerial photograph (Phaneuf 1997, Green 1999). Examples include the advances made recently with interferometric swath bathymetry sonar sensing for very shallow water and shoreline studies, as well as medium-depth water and deep water. Underwater imagery acquisition has taken over where underwater photography left off. Use of such imagery may be hindered by problems associated with stitching together many images where ground control points are not present.

Photogrammetry

Photogrammetric techniques have also been applied to coastal studies. One example is coastal monitoring, where the development of geomorphological models of salt marshes have been based upon mapping techniques using aerial photographs and videogrammetry. A combination of datasets and techniques that draws on recent developments in remote sensing, photogrammetry, and information technology have been shown to be the most useful.

Integration

Not surprisingly, many environmental problems and tasks require multiple sets of data from a wide variety of sources in order to provide the basis for information extraction. It must be remembered that no one source of remotely sensed data can provide all the information; in some cases, additional sources of data or environmental models are required to assist in interpreting remotely sensed imagery.

If, for example, the intention is to simply visually identify coastal vegetation units and types, then no geo-correction may be necessary. However, if there is a need to accurately map units to provide, for example, a vegetation map or to undertake change detection studies, or to undertake any quantitative measurement, then geo-correction will be necessary.

Drawing of unit boundaries on a clear transparency will include error from sources such as the size of the pen tip used, steadiness of the hand drawing the boundaries, and the eye-hand coordination drawing at the scale of the imagery. If the boundaries are subsequently digitised using a digitising tablet, then error will be incurred when tracing the drawn boundaries, resulting from steadiness of the hand and choice of digitiser puck point or run mode. It is also questionable whether or not some boundaries should be represented by hard lines and, if not, how these should subsequently be recorded and represented. Similar considerations need to be taken into account if the tools of a DIP system are used to trace boundaries between visually identifiable and distinguishable units.

Matching Source to Issue

It must be recognised that some remotely sensed data and imagery will not be useful for some investigations and different combinations of imagery and other data, even if gathered at different times, may provide the information required for a particular application when taken together. The image processing techniques used may also determine the extraction of the information. There is a need to match available data and imagery to the task. More often than not, the suitability of remotely sensed imagery is also dependent upon spatial detail, the scale of the application in terms of costs and data handling, and the advantages offered by different sensors to yield specific information of interest.

Resolution

Much interpretation of remotely sensed imagery is dependent upon the ability to differentiate features of interest from their surroundings. While it is sometimes possible to achieve this using a single source and date of imagery, more often than not additional sources (or dimensions) are needed to provide the required clues. Different spectral, spatial, and temporal resolutions may help. The application of different techniques (e.g., digital imaging processing) may also help the end-user determine very subtle differences in the spectral signal sufficient to attach a class or label to the feature (e.g., shallow versus deep water).

The scale and spatial resolution of a satellite sensor may be the most appropriate choice in contrast to aerial photography or other airborne sensors, irrespective of a general perception that spatial resolution is of primary importance.

This also highlights the fact that, while some sensors may offer distinct advantages over others, the choice for a particular task ultimately rests with the nature of that task and the information required. The choice should be determined by the end-user requirements and not a general feeling that, for example, one sensor is better than another.

Scale

The question of scale is also an important factor in remote sensing studies (for example, see Goodchild and Quattrochi 1997). Our much-extended capability to study the environment at a variety of different spatial scales is important in the quest for knowledge and understanding. Satellite remote sensing, for example, has allowed us to develop a better understanding of some of the coastal processes operating at local, regional, and global scales. Matching scale to the issue or task is very important. The advantage of the many different sources of remotely sensed imagery is that they offer a unique set of different scales that can be used either alone or in conjunction with each other, allowing for data mining.

Compromise

In many cases, the realistic choice of remotely sensed imagery for a task ultimately rests with what is available at the time. Sometimes new imagery is not available for a study and, for a variety of reasons (bearing in mind that the imagery may not have been collected for the study or purpose to which it is now being or is intended to be put), the available imagery must be used. In some cases, disappointment may result, as the required information is not contained in the imagery. In other cases, the information extracted is only partially useful. The point to note here is that, for many applications, especially those requiring access to archival data (e.g., change detection studies), a compromise may eventually need to be sought between what data and imagery are realistically and ideally available. In such cases, however, the available remotely sensed imagery, even though not ideal, usually remains useful, even if it is not possible to fully utilise it or to appreciate its full potential.

Extracting Information

Image interpretation can include simple visual inspection of an image or the use of image processing systems that analyse the digital numbers and classify ground features using simple or complex semi-automated computer algorithms. It is considered that image processing and some mapping software can undertake the analysis and classification of ground features much more accurately than the human eye, although there are some pitfalls, and the end-results are not always necessarily as good as the eye-brain combination.

Given a source of remotely sensed imagery, what approaches are open to the end-user for extracting information from it?

Photointerpretation

Aerial photographs, and indeed any imagery (airborne or satellite), can be used in a variety of ways. Typically, the easiest is simple viewing of the imagery, usually in the form of a paper print, although sometimes as a positive or negative transparency. In some cases, this may involve the use of a magnifying glass. Clearly, viewing of a large format image is the easiest. Viewing of a negative or positive transparency requires a light table and, where the images are still on the film roll, can be aided through the use of a pocket stereoscope. Placement of a clear plastic transparency over an image, taped down and using a black or coloured pen, aids interpretation and annotation.

If an image is available as hard copy (aerial photograph: positive/negative transparency or print) or in an electronic or digital image for display on a computer screen, then the image can be viewed and the human "eye-brain" combination used to interpret the image. Imagery can also be in the form of a satellite image, a thermal infrared image, and even a video image.

How is interpretation achieved? With a colour aerial photograph of, for example 1:10,000 scale, the spatial detail visible and the familiar view (with recognisable features) will make a fair amount of sense (even if the end-user is not entirely sure of where the image was taken). Orientation (using other information or a map) also provides an additional aid. To a large extent, orientation within the image is determined by a priori knowledge and the available context (visual or otherwise) provided. When the image is less familiar (e.g., panchromatic, panchromatic infrared or colour infrared, or multi-pectral (blue, green, red, or near infrared bands)), then the extraction of information is probably still largely based upon the detail but may be hindered by the black-and-white "world" presented to the eye or colours that do not correspond to reality. Images, unlike maps, are not usually accompanied by a key or legend until interpreted and classified.

Photointerpretation is a skill that requires considerable expertise, knowledge, and understanding, and above all, plenty of experience. While relatively simple to undertake in practice, attaching "labels" to features recorded on a photograph or other imagery requires an in-depth knowledge and understanding of spectral reflectance curves, physical characteristics of the terrain surfaces, image and sensor characteristics, solar radiation, and the atmosphere, and a local knowledge of the environment. Several photointerpretation factors provide "clues" the photointerpreter uses to identify the features on the imagery, in this case aerial photography (Table 5). To a large extent, spatial resolution of the imagery determines what we can see and subsequently identify. Together, these factors allow us to map spatial units (e.g., coastal vegetation units) and to attach "labels" or identities to these spatial units (e.g., salt marsh and dune). The quality of the aerial photography, the scale, type of photography, and season of the year will help and/or hinder the interpretation exercise.

TABLE 5: "Clues" to Identify Features on Aerial Photography

- Association — contextual information
- Colour — an additional dimension to greyscale
- Shadow — provides a clue to objects with height
- Shape — man-made or natural (straight/irregular)
- Size — dimensions
- Texture — evidence of spatial pattern as a function of the surface (e.g., shadow in vegetation due to canopy structure)
- Tone — grey shades or colour shades associated with the reflectivity/emissivity of the surface

In order to use aerial photography for the task of mapping or map revision, it is necessary to find a way to remove inherent distortions present in the imagery. Distortions are those points on the image are not in the correct planimetric position as they would be on a map. A photogrammetric instrument such as a Zoom Transfer Scope can be used to optically distort the photographic image, in the form of a print, to "fit" a map.

Image stereopairs, if available, facilitate major improvements as far as the potential viewing and interpretation environment are concerned. The use of a pocket or mirror stereoscope provides a clearer, slightly magnified view, as well as a stereomodel of the terrain, dramatically enhanced by magnification resulting from the choice of stereoscope and viewing lenses. The use of stereopairs is the usual choice for photointerpretation, analysis, and mapping exercises. Following a careful set-up procedure for stereoscopic viewing and placement of a clear plastic transparency over the left or right image of the stereopair facilitates interpretation, mapping, and annotation. Stereopairs can also be used for deriving contour maps using, for example, a Kern PG2 Plotter, while the creation of orthophotos and orthomosaics can further render the imagery more applicable for mapping exercises, ensuring planimetrically correct results with the minimum of error. Computer-based solutions can now be used to correct aerial photography held in a digital format, and solutions can be simple (e.g., first order that remove aircraft yaw, pitch, and roll but do not take care of such things as terrain displacement). More advanced techniques of photogrammetry are necessary to create orthophotos. Orthophotos can also be used as prints as well as on a computer display screen. Expertise, knowledge, understanding, and additional sources of data and information will determine what information can be extracted from the imagery. The use of a clear plastic transparency and pen allows interpretation of identifiable spatial units to be extracted from the source imagery as a layer that can then be digitised and transferred to ESRI's ArcView GIS for further analysis.

Digital Aerial Photography

With the development of desktop scanners, it is relatively simple to turn a photographic print into a digital equivalent, albeit with some degradation of the image quality and information content dependent on the scanning resolution, and to view this on-screen while also taking advantage of the image manipulation and processing tools. The value of the image processing tools is somewhat limited by the scanning resolution of the image, which means that zooming into the image reveals the coarseness of the scan pixels (picture elements).

There are obvious advantages to digitising aerial photographs. Multi-pectral bands can be examined side by side in separate viewing ports or windows, and a variety of simple enhancement techniques can be used to visually improve the image contrast and to selectively both emphasise and de-emphasise the information content of each. However, before proceeding, it should be asked whether scanning is worthwhile and what problems are there likely to be (e.g., data conversion and resulting error in, for example, the interpretation).

Converting a Paper (Analog) Print to a Digital Raster Format

Scanning. Turning an aerial photographic print into a digital raster format is now relatively simple and of low cost for those who have the scanning hardware and software.

Scanner Resolution. The typical scanner resolutions are 75, 150, 300, 600, 1200, 2400, 4800, and 9600 dpi and higher (dpi = dots per inch/pixels per inch/bits per inch). Most scanners will scan up to 300 or 600 dpi, the higher resolutions being interpolated. The higher the dpi used, the closer the scanned document will be to the original, but the larger the file size generated. For this reason, most aerial photographs are scanned at a resolution of either 150 or 300 dpi, thereby providing a manageable file size. Below this resolution, the resulting digital image is visually too coarse to faithfully reproduce the original detail. Above 300 dpi, the file size often becomes too large for most desktop systems to handle (either for storage or display (unless you have large amounts of computer storage, plenty of RAM (Random Access Memory), and on-board RAM (4 to 16+Mb) for the graphics display card).

Currently, 300 dpi seems to be a commonly used and accepted file size, although with better graphics display capability, increasing hard-disk storage capacity, new graphics file formats (including the use of image compression techniques), and file compression software such as Mr. Sid from LizardTech and ECW from ER-Mapper becoming more commonly used, this is rapidly changing.

Image File Size

In most cases, aerial photographs are obtained in the standard format of 9" x 9" (23 x 23 cm). At the outset of a study and before proceeding to generate digital imagery, it is important to estimate approximately how much hard-disk storage space will be required for each photograph scanned. This can be calculated as follows:

where is the X dimension of the photograph, the scan resolution, the Y dimension of the photograph, and the number of grey or colour levels (bits).

- 4 bit = 16 levels (colour/greyscale)
- 8 bit = 256 levels (colour/greyscale)
- 24/32 bit = 16 million levels (colour)

For example, a single colour aerial photograph (256 colour – 8 bits) of 23 cm x 23 cm at 300 dpi: ((23 x 300) x (23 x 300) x 8) / 8 / 1,000,000 will require storage space of approximately 47 Mb. Storage requirements for any image of any dimension can be similarly calculated. The major drawback of scanned images is the requirement for storage capacity for large files (1 to n) and the requirement of rapid display, such as a comparison of different dates (1 to n).

It must also be remembered that the user may need more than one image, and in some cases may even generate a new file that comprises a number of scanned images stitched or mosaiced together, or processed. Furthermore, a project may involve multi-temporal and multi-band imagery, all of which increases the storage and RAM requirements of the computer workstation.

Raster Graphics File Formats

As the use of scanned images (many being archival) becomes more popular, it will be necessary to deal with the large image file sizes generated. A number of solutions exist. One is to increase the hard-disk capacity of the computer system available and to archive or back up imagery that may not be needed online. Other solutions involve choosing suitable graphic file formats to work with, ones that include file compression technology. Numerous examples are available, some of which are described as either "lossy" or "lossless." Lossy means that some information contained in the original image is lost when saved (the lossy format), while other formats (the lossless format) involve either no loss or very little loss of information. This loss may be in the detail present in the image or the colour resolution (the number of colours).

Depending upon the objectives of the scanning task, such a loss may not be very important and indeed may not be visually perceptible to the eye. However, where there is a need to retain the detail and colour of the original image, the lossless format is the better option. There are many different graphic file formats currently available, although only a few are probably in regular use for remote sensing and GIS software applications. These include TIFF and JPG as well as other specialised formats such as Erdas Imagine's IMG and the GeoTIFF format. However, there are a number of graphic file translators or filters available to help the end-user convert from one format to another. Most of these, however, are separate from the remote sensing and GIS software applications and may require additional knowledge and expertise.

Image Compression

Mr. Sid (LizardTech) provides file compression ratios of 100:1, which also facilitates transmission over the Internet and partial image retrieval from a larger scene "on the fly." Likewise, ECW compression technology available from ER-Mapper 6.0 Compression Wizard, which offers 10:1 to 15:1 for greyscale and 25:1 to 50:1 for colour.

While a great deal of information can come from visually interpreting images, computer software can also provide advantages. Digital image processing techniques can help extract the information through the application of specialist techniques. However, there are other factors to bear in mind: the use of zoom tools in on-screen visual analysis of imagery can occasionally lead to the loss of spatial context (e.g., interpreting spatial pattern); a sound understanding is needed of the relative merits of different mathematical algorithms used by DIP software for either supervised or unsupervised classification.

Complex Processing

Digital data and imagery require considerable time, effort, and expertise to process and interpret. In general, the more sophisticated the source of the data and imagery, the more sophisticated the information extraction techniques required to make the best use of it (Thomson et al. 1996).

Digital Image Processing

If a DIP system and digital imagery are available, then the software can be used in both a simple and a more complex way. Table 6 lists several terms used in digital imagery.

Simple

The advantages of digital imaging processing techniques and tools are that they are easy to use and are inherently very practical. While the imagery used may suffer from some degradation during the conversion process, the computer-based approach offers unique and practical alternatives to manual interpretation (e.g., easy duplication of imagery for use by more than one interpreter and additional visualisation tools).

Digital image processing software can be used in an elementary way for image interpretation that in effect is an electronic equivalent to the visual inspection of a hard-copy image. Software tools (e.g., pan and zoom as well as the drawing tools of the usual "in-

TABLE 6: Digital Imagery Terms

- Zooming — managing and interpreting, magnification to provide a more detailed, although limited view.
- Band combinations — trial and error process to determine which band combinations yield the most information on satellite and other digital sources.
- Density or level slice — enhance spatial and spectral patterns and processes on satellite imagery.
- Filtering — may or may not enhance or suppress information in images.
- Classification (supervised/unsupervised) — requires a priori or post priori information to aid in the selection of classes or labelling.
- Annotation (use of digital tools to annotate identifiable features; governed by spatial resolution and enhancement techniques used) — makes the best use of digital tools for drawing on a wide variety of identifiable features governed by the spatial resolution and visual enhancement.
- Subsetting — extraction of a manageable portion of an image.
- Blend/swipe/flicker — animated visual overlay for change detection of shorelines, new development, and land-use change.
- Image merging — combining higher spatial resolution with better spectral resolution.
- Image mosaicing — beneficial for coverage of a large area by aerial photographs.
- Image overlay — draping an airborne or spaceborne image over a digital terrain or digital elevation model provides a new visual perspective.
- GIS — integration with other spatial data can aid classification and interpretation.

built" software package) can be used to derive the equivalent of a manual interpretation on-screen.

The use of basic image processing tools requires very little knowledge of either the techniques of digital image processing or the software. The use of simple computer-based image processing tools such as blend, swipe, flicker (Erdas Imagine; www.erdas.com), and different band combination displays and density slicing can aid in getting more information than from the image display alone. Image processing software allows the user to magnify and reduce portions of the imagery very easily, either isolating a feature of interest or setting it within a broader context. This can be aided by reference to other information such as maps.

Advanced

Digital image processing involves the application of a range of techniques that allows the end-user to process digital format data and imagery into information. Initially, this involves pre-processing (preparation), visual enhancement (for visual inspection), and subsequently the application of a variety of more advanced processing (e.g., filtering and principal components analysis), and semiautomated classification. Although most DIP applications follow a similar path, since it involves the use of a set of software tools, how do the end-users know what image processing techniques to use when they are confronted with a specific task? The basic steps in the DIP methodology are outlined below:

- Image display 1 — check
- Pre-processing (e.g., radiometric and geometric correction)
- Image display 2 — corrected
- Image enhancement (e.g., filtering, principal components analysis and HIS)
- Image classification (supervised/unsupervised)
- Error analysis (classification accuracy)
- Image display 3 and hard-copy output

Some Final Guidelines and Tips

Method

- Identify the problem
- Examine the data and image sources available
- Choose data and imagery based after consideration of cost, availability, scale, and spatial, spectral, and temporal resolution
- Choose data and image analysis approach (manual, digital image processing, or GIS)

Some Additional Observations

- Spectral resolution is important. The finer the spectral resolution, the more likely that it will be possible to acquire unique information and differentiate between surfaces exhibiting subtle spectral reflectance or emittance characteristics.
- For large-area coverage, in which large-scale processes are likely to be active, satellite imagery with spatial resolutions of 80, 30, 20, or 10 m are appropriate, as they will clearly show the resulting patterns (e.g., tidal currents). This provides an indication of the spatial scale of the process. For a more detailed examination of such processes, higher resolution imagery should be used.
- High spatial resolution imagery is needed in order to ensure the detection and identification of small features or detail. This will allow investigation of features up to the resolution of the imagery. In some cases, the high spectral reflectance of a feature may make it visible on lower resolution imagery, even though the detail is finer than the resolution of the imagery.
- The need to monitor and map detail will require the highest spatial and spectral resolution imagery available.
- The availability of a wide range of different types of imagery covering a study area is ultimately more useful than a single source for an investigation. The different sources should

be used in a hierarchical fashion, effectively being used to zoom-in on detail in areas where it is necessary and using the lower resolution imagery only for examining spatial patterns and detail at a particular scale.

- Multi-temporal imagery is vital for change detection studies, although some comparisons can be made to maps if the available imagery is at an appropriate scale and can be geo-corrected. Unfortunately, multi-temporal imagery is not always available and certainly not for the specific dates usually required. The availability of imagery for a particular time of day, month, or year may be vital on its own to provide specific information or to differentiate between different surface types. However, the actual available dates may not be appropriate.
- Where different sources of imagery are available, for example, one type of image for each date, then care must be taken in the interpretation of changes since some of the imagery may need to be resampled and apparent visual change may not in fact be real change.
- High-resolution digital data and imagery usually requires and benefits from the use of digital image processing software to process and analyse it. These systems can be used simply to display and interpret the imagery, or the image processing techniques can be used to create new images that may be more visually informative or may, through classification (with or without the aid of the user and ancillary data), lead to the extraction of information.
- All remotely sensed imagery has some potential application to biological and habitat monitoring. The difficulty is knowing whether it will be applicable in a certain situation. Based upon knowledge of the sensor and image characteristics, it should be possible to narrow the ideal choice of imagery suitable for the task or part of the task, and subsequently to adjust this further based on what is actually available.
- In nearly every case, ground truth information is vital for remote sensing studies. This may seem to defeat the purpose of remote sensing, but it is important in defining what is on imagery and for checking interpretations and classifications for accuracy. Ground truthing can include field visits, previous studies, maps, photographs, etc.; in fact, any source of information that can provide a pointer, clue, or confirmation is helpful.
- Computer technology significantly increases the opportunity to extract information from the imagery available for experimentation, and also to make increased use of the imagery and information in the long term. It must be remembered, however, that time spent on gathering, converting, and processing digital imagery may not yield much more information than the use of simple tools and visual inspection; the input of time may in some cases be disproportionate to the information acquired.
- Ultimately, most processing of remotely sensed imagery (manual or computer-based) involves visual interpretation and depends upon the viewing environment and the end-user. Visual interpretation is limited by our eye-brain combination and, in some cases, the subtle differences between surfaces may only be brought out through computer processing.
- Simple visual approaches to image interpretation may be all that is necessary (e.g., for detection, identification, and simple mapping). For more advanced applications, for example, where the derivation of numerical data is a vital part of the task (determining actual change from Time 1 to Time 2), it will be necessary to correct the imagery for inherent distortions, to consider resampling and scaling, and, with this, to record information about the errors associated with the measurements.

Conclusions

Remote sensing is an excellent source of data and information about the coastal environment. One of the key advantages is that it is a "snapshot" of the real world. People instinctively relate to and recognise what is shown in an image. Despite this, remotely sensed data are not as widely used as they could or should be, because those who need to use the data often are not familiar with its utilisation or automatically assume that aerial photography is the best source of data. In reality, understanding that each sensor provides data and imagery with its own set of benefits and limitations is the key to its use. The spatial resolution of an image (rather like the scale of a map) is the basic limit to the amount of information that an image contains when considering spatial relationships even between spectral data. On this basis, imagery can be organised with a hierarchical structure, from a low- to a high-spatial resolution. By determining the spatial, temporal, and spectral requirements of an environmental issue, it is possible to understand the information needed for solving that issue and to match these up with the corresponding characteristics or utility of an image. In this way, criteria can be developed to guide the user to the correct image for a particular issue.

Many difficulties exist when trying to utilise remote sensing technology in the environmental management arena. These include a lack of knowledge surrounding the types of imagery and what they can be used for, image processing techniques to extract useful information, and a general "slowness" to accept information technology in the management workplace. However, such a system could effectively help to "operationalise" remote sensing in this area, an objective that it is highly important to meet.

A great deal of remotely sensed data and imagery has been and still is being collected. Some sources are almost continuous, while others are flown more intermittently or specially for new projects. Over time, spatial, spectral, and temporal resolution of airborne and spaceborne sensors has improved considerably. With the advent of information and computer technology, more remotely sensed imagery is digital. Furthermore, more data and imagery are now available for digital image processing on desktop computers by persons who are not necessarily specialists in the field of digital data handling.

As the importance and value of remotely sensed data are recognized, either as a single or a complementary source or integrated with other types of geospatial data, additional users will be needed. These users will become more actively involved in the interpretation and analysis of the data and imagery that will enable a wide range of information to be extracted and used for mapping, monitoring, and modelling.

Software has become more user-friendly over time and, together with tutorials, this has helped the applications specialist to make wider use of the data and imagery than before. However, there is a need to further develop the software to allow more people to make use of the data and imagery. At present, many potential users of remotely sensed data and imagery do not know which data and imagery are appropriate to their problem, where to find it, and how to process it into information. To this end, there is a need to provide greater awareness of remote sensing data and imagery, its sources, and both the simple and more sophisticated ways to process the data into information.

A number of recent developments have helped make remotely sensed data and imagery more usable. These include:

- Image compression: allowing large digital datasets to be communicated, manipulated, and viewed, for example, across the Internet
- Rapid evolution of computer hardware and software: processing power and functionality
- Education and awareness: a number of recent publications focusing on the practical use of remotely sensed data and imagery

- Commercialisation of remote sensing: custom specification of image acquisition and use of the Internet for online digital image processing
- Artificial intelligence: knowledge bases and expert systems for image interpretation
- Metadata: growing requirements for documentation of data and imagery allowing for the development of searchable metadata catalogues

It is recognised that a great deal can be achieved with aerial photography and the higher resolution sensors using simple visual photo/image interpretation. To do this, the end-user must be provided with knowledge to help them choose the right data and imagery for the job or task as well as appropriate interpretation, analysis, and processing techniques for their needs. Image data are only part of the solution in most cases and, depending upon the task, a single source of imagery or multiple sources may be important in order to make the best use of the spatial, spectral, and temporal resolutions available.

It must be noted that remote sensing, GIS, and related technologies are only tools; they are tools of our own invention and as such are a product of their time and the sophistication of our technology at that time. They are subject to the limitations of our knowledge and understanding, and they have specific applications. Rather than be the answer to all our data and information problems, they are one way by which data and information can be gathered. Remote sensing technology provides an opportunity to gather more data, some of which is unique, and ultimately the chance to gain a greater knowledge and better understanding of our physical and human environment. In itself, the technology is not a solution to environmental problems or management tasks, but it is a means by which we can acquire some of the data we need to inform, plan, and make decisions, to process, handle, analyse, and visualise the data, and to acquire information that can be utilised in planning and decision-making.

It is important, however, to appreciate and to understand the origins and developments of this technology, our reasons for using it, and the advantages and disadvantages, such that it may be applied in a careful and considered way without too great an expectation or disappointment when the technology does not seem to deliver what we perceive that it should.

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Glossary of Terms

(sourced and adapted from Websites below)

Aerial Photography: Photography taken from an aerial or airborne platform.

Electromagnetic Spectrum: The wavelengths of electromagnetic radiation extending from the short wave to the long wave.

Ground truth Data/ Ground truthing: Field data or information about a feature.

Interferometry: Combination of two radar measurements of the same point on the earth's surface, taken at the same time, but from slightly different angles, to produce stereo images.

Metadata: Data or information about information.

Mosaic: A group of overlapping remotely sensed photographs or images that have been matched and balanced to form a single image.

Orthophoto: An aerial photograph that has been rectified to remove topographic distortion.

Panchromatic: A single band or monochrome photography or imagery.

Photogrammetry: The science dealing with the 3D effects and methods by which these effects are produced.

Planimetric: Planimetry involves the identification and geo-location of basic features on the Earth's surface in the x, y plane.

Radiometer: An instrument for quantitatively measuring the intensity of electromagnetic radiation in any part of the electromagnetic spectrum.

Raster: Raster data consisting of an array of grid cells (usually square).

Spatial Resolution: The smallest size and object to be detected.

Spectral Emittance: The power radiated per unit area of a radiating surface in a defined waveband.

Spectral Reflectance: The ratio of reflected radiation to incident radiation on a surface in a defined waveband of the electromagnetic spectrum.

Spectral Resolution: The division of electromagnetic spectrum sensed.

Stereomodel: Formed by the brain using the normal process associated with binocular vision

Stereopair: An overlapping pair of aerial photographs.

Stereoscope: An instrument (pocket or mirror) that provides a 3D view of a stereopair.

Temporal Resolution: The frequency of remote sensing interval.

Zoom Transfer Scope: An instrument for the analysis of stereophotographic transparencies or prints to transfer information to base maps.

Additional Resources

Books — additional reading materials, websites, and other resources

Remote Sensing

Gibson, P.J., 2000, Introductory Remote Sensing: Principles and Concepts, (London: Routledge), 184 pp.

Jensen, J.R., 2000, Remote Sensing of the Environment: An Earth Resource Perspective, (New Jersey: Prentice-Hall), 544 pp.

Lillesand, T.M. and R.W. Kiefer, 2000, Remote Sensing and Image Interpretation. 4th Edition, 724 pp.

Digital Image Processing

Gibson, P.J. and Power, C.H., 2000, Introductory Remote Sensing: Digital Image Processing and Applications, (London: Routledge), 249 pp.

Jensen, J.R., 1996, Introductory Digital Image Processing: A Remote Sensing Perspective, (New Jersey: Prentice Hall), 318 pp.

Mather, P.M., 1999, Computer Processing of Remotely-Sensed Images: An Introduction. (Chichester: Wiley and Sons), 292 pp.

Websites

Information

Glossary of Remote Sensing Terms

http://earth.fhda.edu/curriculum/remote-sensing/
http://fwie.fw.vt.edu/tws-gis/glossary.htm
http://www.ccrs.nrcan.gc.ca/ccrs/learn/terms/glossary/glossary_e.html
http://www.casde.unl.edu/vn/glossary/intro.htm
http://www.unesco.org/csi/pub/source/rs15.htm#I

Coastal

http://gsca.nrcan.gc.ca/coastweb/sitemap_e.php

Remote Sensing

http://www.itc.nl/~bakker/rs.html
http://www.ccrs.nrcan.gc.ca/ccrs/homepg.pl?e
http://earth.esa.int/
http://earthpace.com/nepaM/emergingtechsatellite.htm

Kite Aerial Photography

http://arch.ced.berkeley.edu/kap/
http://www.dolphinazur.nl/kapnet.html
http://www.fortunecity.com/marina/nelson/479/
http://www.harb85.freeserve.co.uk/
http://members.aol.com/mjbrown/

Balloons

http://www.ternstyle.com/
http://www.floatograph.com/

Model Aircraft and Helicopters
http://www.hicam.com.au/
http://www.squid-ink.com/hpn/rc-photos/
http://www.highspy.co.uk/

Model Rockets
http://astrocam.aea6.k12.ia.us/
http://straylight.dhs.org/rocket/
http://ourworld.compuserve.com/homepages/pagrosse/h2oraerialcameraMkI.htm

Using Aerial Photography
http://ads.ahds.ac.uk/project/goodguides/apandrs/

Remote Sensing and Aerial Photography
http://www.colorado.edu/geography/gcraft/notes/remote/remote_f.html
http://www.wes.army.mil/el/emrrp/emris/
http://www.kodak.com/US/en/government/aerial/faq/aerialOrSatellite.shtml
http://www.unesco.org/csi/pub/source/rs14b.htm

Image Compression
http://www.lizardtech.com
http://www.earthetc.com

Modeling
http://www.ceh.ac.uk/subsites/seo/bmg/landsurface.htm

Data and Imagery Sources
http://www.terraserver.com/
http://www.lib.berkeley.edu/EART/aerial.html
http://libweb.uoregon.edu/~map/
http://mapping.usgs.gov/www/products/status.html
http://www.aerialarchives.com/main.html
http://seawifs.gsfc.nasa.gov/SEAWIFS/IMAGES/CZCS_DATA.html
http://www.nioz.nl/loicz/firstpages/data/global.htm
http://www.ccrs.nrcan.gc.ca/ccrs/data/order/details_e.html
http://www.infoterra.com
http://www.getmapping.com
http://terraserver.homeadvisor.msn.com/

Sensors

Aerial Photography
http://terraserver.homeadvisor.msn.com/

Airborne
http://www.itc.nl/~bakker/airborne.html

CASI
http://www.itres.com/docs/casi2.html
http://www.itres.com/docs/ssystems.html
http://www.csc.noaa.gov/products/maine/html/casi.htm

CZCS
http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/OB_main.html
http://daac.gsfc.nasa.gov/data/dataset/CZCS/index.html
http://www.sat.dundee.ac.uk/czcs.html

Digital Aerial Photography
http://www.infoterra-global.com/dig_ap. html

Envisat
http://envisat.esa.int/

Landsat
http://geo.arc.nasa.gov/sge/landsat/landsat.html
http://landsat.gsfc.nasa.gov/
http://edc.usgs.gov/glis/hyper/guide/landsat

LIDAR
http://www.aeromap. com/lidar.html
http://www.itc.nl/~bakker/lidar.html
http://www.ioe.ucla.edu/clear/about.htm
http://lidar.wff.nasa.gov/atm/rst97/
http://www.geolas.com
http://www.csc.noaa.gov/beachmap

MODIS
http://modis.gsfc.nasa.gov/

Radar
http://www.itc.nl/~bakker/sar.html
http://www.space.gc.ca/csa_sectors/earth_environment/radarsat/default.asp
http://www.rsi.ca/home.htm

SeaWiFS
http://daac.gsfc.nasa.gov/data/dataset/SEAWIFS/index.html
http://www.nioz.nl/loicz/firstpages/data/global.htm

SPOT
http://www.spot.com/
http://www.spotimage.fr/home/

Thermal
http://www.infoterra-global.com/Thermal%20airborne%20surveys%20from%20NRSC.html
http://www.thermal-survey.co.uk/t_aerial.htm
http://www.airtargets.com.au/aaaars2.html
http://teachserv.earth.ox.ac.uk/nasa/Sect9/nicktutor_9-1.html

Video
http://www.islandnet.com/~cori/capabilities/aerial.htm
http://www.geo-3d.com/a_videoaerienne.html
http://gsca.nrcan.gc.ca/pubprod/coastalvideo/index_e.php

Tutorials

Image Processing Methods
http://coastal.er.usgs.gov/wetlands/ofr97-287/index.html
http://rst.gsfc.nasa.gov/Front/tofc.html
Coastal
http://rst.gsfc.nasa.gov/Sect1/Sect1_1.html

Remote Sensing
http://www.gis.wau.nl/girs/projects/rsbasics/06digitalremotesensingparta/
http://gislounge.com/ll/remotesensing.shtml
http://mercator.upc.es/tutorial/table.html
http://rst.gsfc.nasa.gov/
http://aria.arizona.edu/courses/tutorials/welcome.html
http://www.newc.com/rsat/tutorials.html
http://www.ccrs.nrcan.gc.ca/ccrs/learn/learn_e.html
http://www.earthsensing.com/rssg/exercise.html
http://nasa.utep. edu/paces/
http://www.gisdevelopment.net/tutorials/tuman008.htm
http://www.tnris.state.tx.us/ResearchCenter/RemoteSensing/aerial.htm
http://www.research.umbc.edu/~tbenja1/
http://orbit-net.nesdis.noaa.gov/arad/fpdt/tutor.html

GeoImaging
http://imaging.geocomm.com/education/tutorials/

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