National Centre for Instrumentation &
Marine Surveillance
&
National Remote Sensing Centre Ltd.

NRA Applications of Remotely Sensed Data

NRA
National Centre for Instrumentation and Marine Surveillance

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Report for the National Rivers Authority

NRA Applications of Remotely Sensed Data

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Executive Summary

This document has been produced to serve as both an introduction to the National Rivers Authority (NRA) applications of remotely sensed data and a reference manual to consult as and when required. Use of remote sensing for environmental monitoring is growing rapidly because of its relative low cost compared to ground survey and the enormous potential for change detection. Potential for use of remotely sensed data within the NRA is great, with applications in every sector from Water Quality to Conservation. This report highlights a few applications some of which are actual projects being undertaken at present. The National Centre for Instrumentation and & Marine Surveillance, South Western Region, is leading the take-up of remote sensing in the NRA, with airborne surveys of the whole UK coast three times a year.

In this report the general principles of remote sensing are considered in order to give the reader a basic understanding of the concepts involved. Sections 2, 3 and 4 list spaceborne, airborne and planned future sensors respectively, the specifications of the data obtainable from each sensor is considered, in order that an informed decision can be made regarding data acquistion. Details of how catalogue searches for the imagery are made and an explanation of the search results are also given. An approximate cost of each data type is included, to serve as an indication only, actual data list prices can be obtained from the National Remote Sensing Centre (NRSC) as required. Section 5 considers the processing requirements of remotely sensed data in order to apply them to NRA applications, examples of which are examined in Section 6.

If the reader has a specific remote sensing application in mind, yet is unsure of its suitability or practicalities, advice can be sought from NRA's National Centre for Instrumentation & Marine Surveillance (NCIMS), South Western Region by contacting Nick Holden or Richard Saull at Rivers House, Lower Bristol Road, Bath or telephone 01278 457333.

Contents

List of Figures

Section No.5 Digital Image Processing

Section No.6 NRA Applications

Section No.1

What is Remote Sensing?

1.1 INTRODUCTION

Remote sensing is the science of observing and gathering information about objects from a distance. This statement conceals a subject of great depth and richness, with applications in many areas of scientific research, environmental management and planning, and resource exploration. In recent years, "remote sensing" has become associated with satellite, airborne and computing technology. These technologies have indeed greatly increased our capacity for observing and understanding our world, but remote sensing has a longer history and broader scope than these areas might suggest.

This section serves a brief introduction to the basic principles of remote sensing, the components of a remote sensing system, the key concepts of remote sensing data, and how these data are handled in an operational manner.

1.1.1 Definition of Terms

Remote sensing has a considerable amount of "jargon" associated with it; either wholly technical terms, or more general words which, in this context, are used with a different or more precise technical meaning. In either case, the lay person may find the use of such terms confusing. Where a technical term is introduced, it will be defined so that the general reader will find it easy to relate to the intended concept. It should be borne in mind, however, that certain terms (for instance, the term *radiance*) may also have a more precise, scientific definition which is outside the scope of this discussion. A Glossary, at the end of this report, defines some of the more complex terms highlighted thus "*radiance*" in the text.

1.2 REMOTE SENSING SYSTEMS

A generic remote sensing "system" will consist of three components: the *sensor* , which records information, the *platform* , which carries the sensor to a position where it can observe its intended target, and a data storage and *image processing system,* usually a computer.

1.2.1 The Electromagnetic Spectrum

The foundation of remote sensing is electromagnetic radiation. What we perceive as light can be thought of as a "wave" in the electrical and magnetic fields surrounding the Earth, characterised by wavelength and frequency - hence the name electromagnetic radiation. Figure 1.1 gives a diagrammatic representation of the electromagnetic spectrum.

Areas of the spectrum with a common characteristic are referred to in remote sensing parlance as *wavebands* . The human eye, for instance, perceives this radiation within a range of wavelengths, between 0.4 and 0.7 microns (µm), corresponding to the different colours we see in the rainbow spectrum; this is known as the visible waveband. The region at slightly longer wavelengths than visible red light is referred to as the near infra-red waveband (usually abbreviated to NIR). Figure 1.2 gives a list of the most commonly used wavebands, their characteristics and usual abbreviations.

The visible waveband is only a small part of the full electromagnetic spectrum, which ranges from radio waves and microwaves at one end, though thermal infra-red (heat) to middle and near infra-red, visible and ultra-violet wavebands to X-rays and gamma rays at the other.

Contemporary remote sensing techniques usually confine themselves to the visible -infra-red-thermal, and the microwave wavebands, all of which can carry useful information about the Earth's surface. In order to fully utilise these sources of information, however, more technology is needed.

1.2.2 Sensors - Data Recording Devices

The term "sensor" is used to describe a device which gathers and records information, usually by recording the amount of energy it receives from an object. The phrase "amount of energy" is a somewhat imprecise term, since it can be defined in different ways for different purposes; the term *radiance* is a useful shorthand. Sensors can be further divided into *passive* and *active* sensors. A passive sensor is a device such as a camera which simply records the amount of energy falling upon it. An active sensor is a device such as a radar, which sends out a signal, and then records how much of that signal is reflected back to it from the target.

When considering any remote sensing system, the *resolution* of the system is an important concept. Resolution can be defined as the smallest detail or change in a parameter that the system can detect. There are four important general quantities which will describe the performance of any remote sensing system:

- Spatial Resolution: This governs the smallest area visible in the remote sensing data or image, and can range from centimetres with low-flying airborne systems, to kilometres from some weather satellites.

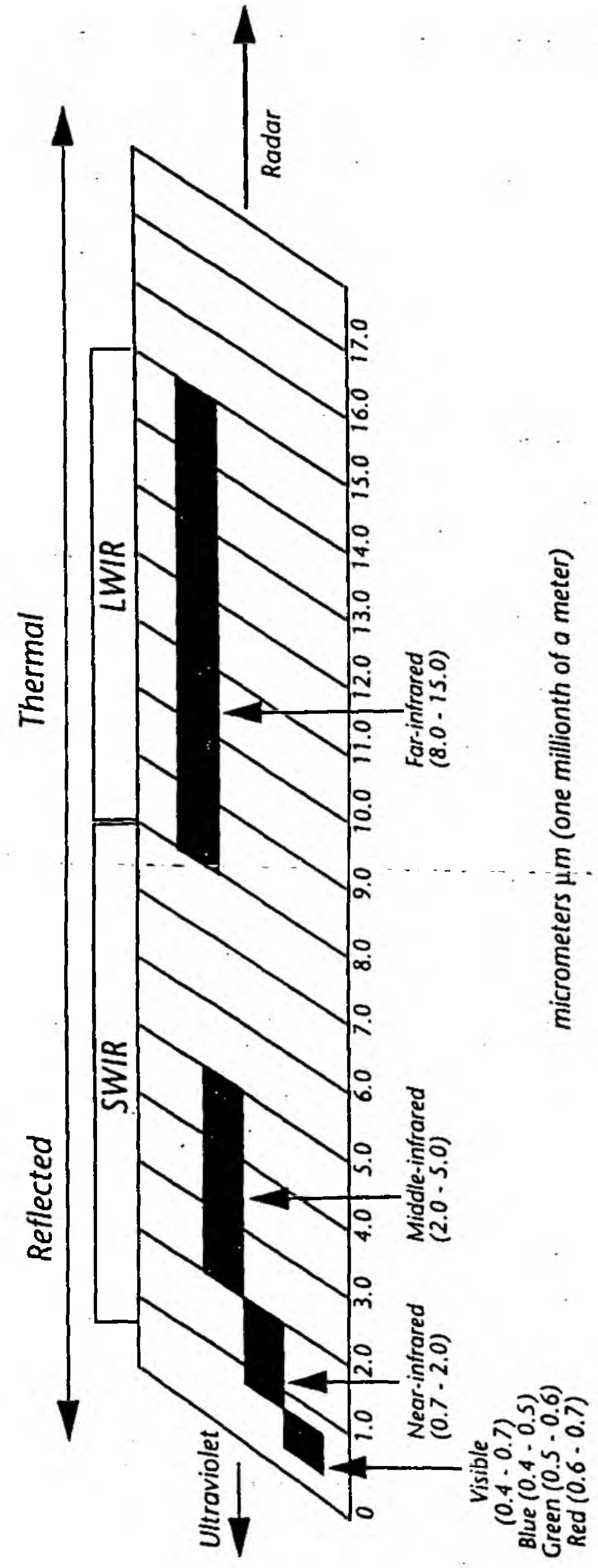


Figure 1.1 The Electromagnetic Spectrum (Source: Erdas Field Guide, 1993)

Band Name	Common Abbreviation	Wavelength Range	Uses
Ultra Violet	UV	0.003 µm - 0.3 µm	Laser fluorescence, oil spill determination
Visible	VIS	0.3 µm - 0.7 µm	Colour composites, ocean colour, vegetation studies
Near Infra Red (Reflected Infra Red)	NIR	0.7 - 0.9 µm	Vegetation studies, atmospheric correction
Short Wave Infra Red	SWIR	2 µm - 8 µm	Water vapour, soil moisture, geological discrimination, atmospheric correction
Middle Infra Red	-	2 µm - 5 µm	As for SWIR
Thermal Infra Red	-	8 µm - 15 µm	Temperature, sea surface temperature
Microwave	-	10 mm - 1 m	Radar, SAR, SLAR ; Passive microwave studies

Figure 1.2 Commonly used Wavebands
(Source: Erdas Field Guide, 1993)

- Temporal Resolution: This refers to the time interval between acquisition of successive images of the same scene or data from the same place.
- Spectral Resolution: This refers to the range of wavelengths of light, and wavelength intervals which the system responds to (also known as *spectral wavebands*, or *bands*).
- Radiometric Resolution: This refers to the smallest difference in radiance, or "brightness", that the sensor system can detect.

Eye and Brain

The human observer is an integral part of many remote sensing systems. The eye collects light (electromagnetic radiation) reflected from an object and forms an image which is then interpreted by the brain. However, the eye / brain combination is limited by the range of wavelengths it can detect, and by the amount of information that it can record and process.

Photography

The invention of photography provided, for the first time, a means of accurately and permanently recording a scene. Photographic remote sensing came of age with the advent of flying. Interpretation of aerial photographs now forms an important field of remote sensing in its own right. Although technologically not as sophisticated as digital scanners, photographic instruments are still widely used for many applications, such as mapping & high resolution surveys.

Digital Scanners

This class of sensor uses electronic components rather than photographic film to record information. Whereas a film records the radiance falling on it by means of the shade of grey in the photograph, a digital scanner converts radiance into a digital number which can be stored on a computer tape. Scanners currently represent the "state-of-the-art" in passive sensor design, and are mounted both on satellites and aircraft. They have the advantage over photographic devices, in that a digital scanner can record a number of separate images in discrete wavebands. These images, stored as digital files on computer disk, can be easily processed and manipulated in various ways using the appropriate software. This is much easier to do than processing of photographic prints and negatives. This subject is discussed at greater length in Section 5 on general processing requirements.

Imaging Spectrometers

"Conventional" multispectral digital scanners usually have a small number of fairly broad wavebands, covering discrete, non-adjoining portions of the spectrum. For example, the Thematic Mapper scanner system on LANDSAT-5 has seven bands in the visible, near infra-red and thermal regions. Each of these bands span a range of wavelengths about 0.1 μm wide. (e.g. TM Band 2, generally described as "visible green", images light with wavelengths between 0.52 μm and 0.60 μm).

In contrast, imaging spectrometers are advanced scanners which can acquire a scene in a large number of very narrow, contiguous wavebands. For instance, the airborne CASI system has about 280 bands with an average width of about 0.02 μm, spanning the entire range of wavelengths from the visible blue to the mid infra-red. The large number of images of the same scene across this range of wavelengths forms what is known as a *hyperspectral* dataset, enabling the construction of a continuous reflectance spectrum for every pixel in the image. This in turn allows ground cover types or materials to be identified on the basis of characteristic peaks or troughs in the reflectance spectrum, a so-called *spectral signature*, details of which may be lost in the broader bands of conventional scanners.

Imaging spectrometers are generally airborne systems, although spaceborne instruments, such as MERIS on the European ENVISAT mission, are proposed for the next few years.

Imaging spectrometers are discussed further in Section 3 on airborne sensors.

Radar

Radar systems are now a familiar part of the modern world, having been in use since the Second World War. The name is an acronym of Radio Detection and Ranging. The basic principle is familiar to most people, and is that of an active sensor; the radar instrument emits a burst of radio waves some of which is reflected back from the ground or other objects. The strength of this reflection, or "echo", and the time delay between the emission of the initial burst, and the return of the echo, is measured by the instrument and converted into the distance between the sensor and the object. This is the principle on which radars used as detection devices work, for example, in air traffic control.

Synthetic Aperture Radar

While the radar principle described above can also be used to construct an image, this is unworkable in practice. The spatial resolution of such a system, i.e. the smallest object detectable, depends in part on the size of the antenna used to generate the initial burst; the longer the antenna, the better the resolution. To build a conventional radar system with sufficient resolution to be of use (particularly from space) would require an antenna many hundreds of metres long. This is clearly impractical. A recent development is that of Synthetic Aperture Radar, or SAR. This measures the returns, not just from one pulse, but from many pulses from an extended area of the Earth's surface. These returns, and the time relationships between them, are combined mathematically, to synthesise the effect of a much larger antenna, achieving a high spatial resolution. For instance, the SAR instrument carried by the ERS-1 spacecraft, can produce images with a nominal ground resolution of 12.5 m.

The interpretation of SAR imagery is a specialised area in itself. Many physical parametres have an expression in SAR imagery, such as soil moisture, wave height, sea surface topography, and so on. Numerous algorithms are being developed to extract this information.

Most modern radar and SAR systems use wavelengths of the order of several centimetres. According to current definitions, these are microwaves rather than radio waves, which are generally defined as having longer wavelengths, of the order of metres, tens of metres, or hundreds of metres. However, the name radar has been retained, and refers to microwave instruments as well as those operating with radio waves.

Side-Looking Airborne Radar (SLAR)

SLAR is more of a technique than a specific instrument, consisting of a radar-type system (conventional or synthetic aperture), mounted on an aircraft and imaging a swath to one side of the aircraft's flight path. SLAR can be used to obtain radar imagery at higher spatial resolutions than satellite mounted instruments. SLAR imagery also has characteristics due to its oblique viewing angle, which can yield other sorts of information, e.g. on terrain or local topography.

Laser sensors - LIDARs and Flurosensors.

This final class of sensor is an active system, utilising a laser beam, usually working at ultra violet or visible wavelengths. The main type of laser system is the *LIDAR*, which works in a manner similar to radar, but using the laser beam instead of a microwave or radio beam. LIDARs find application in many areas, such as bathymetry, atmospheric chemistry studies and air pollution monitoring.

Another laser application exploits the fluorescence properties of many materials. An example of this is chlorophyll detection in water bodies. A visible-wavelength laser stimulates the chlorophyll to fluoresce at a particular wavelength, which is then detected by a sensor on the aircraft. The intensity of this fluorescence radiance can be calibrated in terms of amount of chlorophyll present. This technique is known as Laser Induced Fluorescence (LIF). Laser sensors and their applications are discussed further in Section 3 on airborne sensors.

1.2.3 Platforms - Sensor Carriers

The vehicle which carries the sensor is known as the *platform*. As with sensors, there is a wide range of type and sophistication of platform ranging from hand-held devices to satellite systems. Figure 1.3 gives an overview of different types of platform in diagram form. For most purposes, though, the two most important classes of platform are *spaceborne* and *airborne*.

Spaceborne

The development of space travel, beginning in the 1950s, opened up a new dimension of possibilities for observing the Earth. A satellite orbit can observe a large swathe of the Earth's surface on a regular basis, including very remote areas such as the deep ocean which may not be regularly accessible even from the air. Spaceborne platforms include manned missions; indeed, the field of remote sensing from space was given some of its early impetus through photographs taken in the 1960s and 1970s by the crews of Soviet and American "space race" missions: Apollo, Mercury, Gemini, Soyuz, Skylab and more recently, from the Space Shuttle. However, the vast majority of routine remote sensing data returned from space comes from unmanned satellites, mostly through so called "earth resources" or *Earth Observation* satellites such as the American LANDSAT series, and the European SPOT and ERS-1 satellites.

These unmanned spacecraft can be divided into two types, depending on what kind of orbit they occupy. Spacecraft such as ERS-1 are *polar orbiters*. They circle the Earth at a distance of several hundred kilometres, in an orbit such that they travel in a north - south fashion over (or close to) the poles. In this way, these satellites can observe almost all of the Earth's surface as the planet rotates beneath it. A particular type of polar orbit is the *Sun-synchronous orbit*; this is an orbit such that the satellite crosses points on a given circle of latitude on the Earth at the same local time each day. This allows the geometry of the Sun, Earth and sensor to remain the same for a given scene acquired on sequential orbits, which in turn makes it easier to compensate for illumination differences.

An important concept when discussing satellite orbits is that of the *repeat cycle*. This is the time interval between the satellite passing over the same point on the Earth's surface, also known as the *revisit time*. There is a trade off between this quantity and global coverage, in terms of the spacing of the orbits across the globe. Figure 1.4 illustrates this point, using ERS-1 orbital tracks. An orbit with a short repeat cycle will pass over certain points frequently, but large areas of the Earth's surface will be missed. With an orbit which covers the ground more thoroughly, the repeat cycle may be very long, perhaps hundreds of days before the satellite passes over exactly the same point again. Which configuration is appropriate depends on the application of the satellite and its mission.

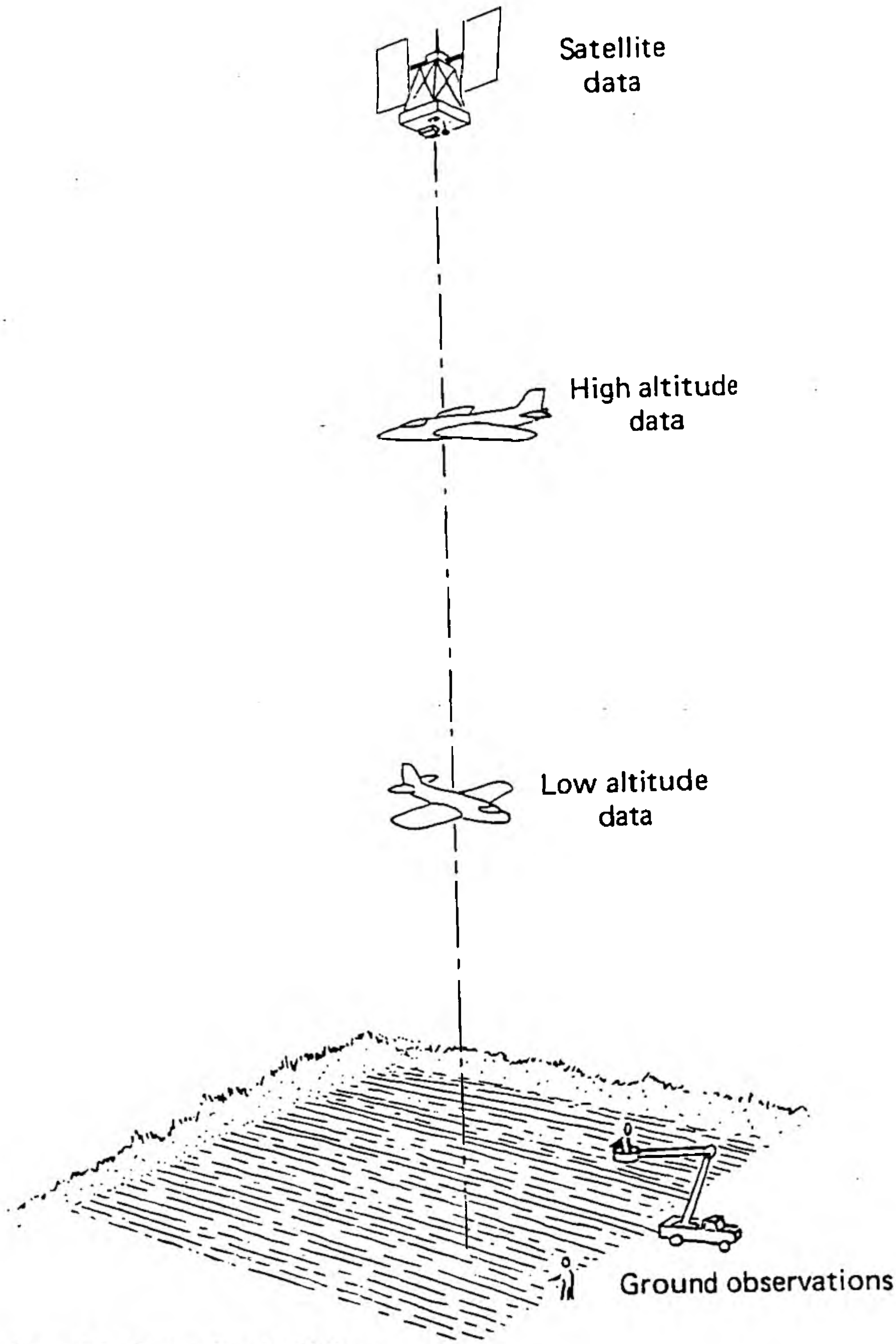


Figure 1.3 Remote Sensing Platforms

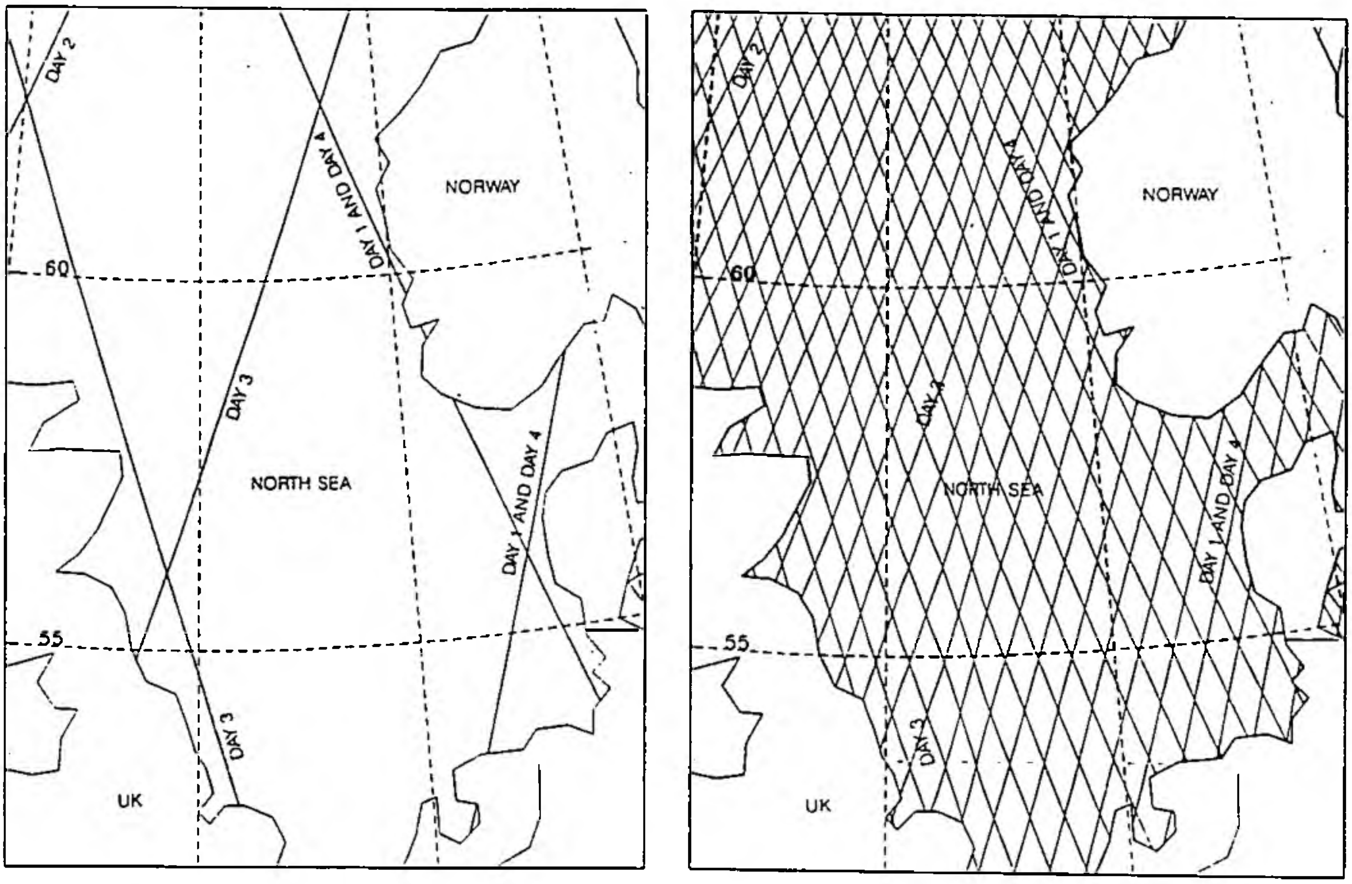


Figure 1.4 ERS-1 Orbital Tracks over the North Sea. A comparison of the density of Radar Altimeter tracks over the North Sea using 3 day and 35 day repeat cycles. (Source: ERS User Handbook, 1993)

In contrast to polar orbiters are the satellites in a *geostationary orbit*. These satellites circle the Equator at a distance of about 36,000 km. At this distance, the time for the satellite to complete one orbit is exactly the same as the time for the Earth to spin once on its axis; the satellite thus appears to remain stationary in the sky, over the same point on the Equator. This is the favoured orbit for communications satellites and some weather satellites, such as METEOSAT, which can observe the disk of the whole Earth at once. However, geostationary orbit has a limited value in Earth Observation studies, as the distance from the Earth is far too great to obtain the high spatial resolution necessary for many applications.

Airborne

Airborne platforms include balloons, helicopters and, most commonly, light aircraft. Until the late 1980s, most airborne remote sensing was done using photographic cameras. The development of digital scanners for satellites has now expanded to smaller systems for use in aircraft. Airborne remote sensing has the advantages of being able to get "closer" to the subject than satellites can, resulting in greater detail and spatial resolution. Temporal repeat of the area of interest is not restricted by satellite orbit, allowing imaging over the tidal cycle, which important in coastal surveys. Also, cloud cover need not be a problem in image acquisition, as the aircraft can simply fly beneath the cloud layer.

Airborne platforms, particularly a light aircraft, are generally much less stable than a satellite, being subject to buffeting by winds and air turbulence. This can be compensated for by use of various motion sensing systems, which keeps track of the exact motion of the aircraft, and enables the image to be accurately geometrically corrected for this. In particular, NRA aircraft flying the CASI system are equipped with automatic roll correction systems, and a *global positioning system* (GPS) which can plot the aircraft's position at any given time to an accuracy of around 10 metres. This information can then be used to *geocorrect* the scene to a given map reference system; this can be done automatically with CASI data. Geocorrection is discussed further in Section 5.6.

1.2.4 Data storage and Processing

Remote sensing data, especially from satellites, are now acquired, handled and stored almost exclusively as *digital* data, i.e. the radiances measured by the sensor from each point on the ground are represented by numbers, held in a file on computer tape or disk. Until the mid 1980's, only large mainframe computers had sufficient power and storage space to process remote sensing data effectively.

However, computer technology has progressed rapidly in the intervening time, and sufficient computing power is now available on mini computers, such as Sun Microstations, and even on some new PC's, with commercially available image processing software packages.

Improvements in presentation, such as "window" systems and *graphical user interfaces* (GUI's) based on graphical representations operated through a mouse, rather than typing commands at a keyboard, mean that people without formal programming training can easily carry out complex image manipulations.

Improvements in data storage media, too, have allowed more information to be stored more compactly than was possible a few years ago. The development of High Density Data Tape (HDDT), optical disk and CD-ROM now allow large quantities of information to be stored on compact devices. Again, this subject is discussed in greater depth in Section 5 on general processing requirements.

1.3 SCOPE OF THIS REPORT

This report first considers the remotely sensed data which are available from spaceborne, airborne and future sensors. The datasets are explained by a number of criteria including data availability, appropriate scales, and details of the wavebands used. Having described the data available, with pictorial examples, details how each of the satellite data sets can be obtained is considered. All the satellite data described can be obtained through the National Remote Sensing Centre (NRSC). The National Rivers Authority's National Centre for Instrumentation and Marine Surveillance (NCIMS) maintains an extensive archive of CASI data of the whole coastline of England and Wales, acquired since 1991 as part of its remit to survey the condition of the coastal zone out to three miles offshore. This dataset is regularly updated and further details are included in Section 3, Airborne Data.

Having considered the data, the general processing requirements for obtaining meaningful information from these data are discussed. Many of the services can be provided in-house by the NRA National Centre for Instrumentation and Marine Surveillance or by external agencies such as NRSC. Finally, a number of NRA application case studies are used to highlight areas where remote sensing can make a useful contribution to the core functions of the NRA and other Environmental Agencies.

Section No.2

Spaceborne Sensors

2.1 INTRODUCTION

These sensors are carried on polar-orbiting satellites, which circle the globe repeating their coverage over a particular region at regular intervals. These repeat frequencies range from twice a day to once a month depending on the size of area imaged, the larger the area the more regularly it is covered. The two main sensor types carried are classed as passive and active. Passive sensors record the radiance received giving details of the earth and atmosphere. Active sensors use microwave or radio frequency energy to illuminate the target. In short, the instrument sends out a burst or pulse of energy and then "listens" for the echo.

To decide on the best data type for a particular application, image details are required. The following section lists details of the currently available satellite imagery by certain criteria such as availability, suitable scale and approximate cost. Of these criteria, *spatial resolution* is extremely important, it describes the ground footprint portrayed by each data sample (pixel) in the image. For example, if the spatial resolution is 1km, only one sample is taken in each kilometre square and the result averaged over that area. In this instance a maximum scale for interpretation or display of 1:1,000,000 is appropriate. To zoom in on an area of interest, a higher spatial resolution is required such as from the Landsat satellite, Thematic Mapper Sensor (30 m), or even better the high spatial resolution of aerial photography (<1m). This spatial resolution of the data is best understood visually by looking at the plates and figures included in this report.

Data Acquisition

Should you wish to acquire any of the data types listed you can obtain advice from NCIMS and NRSC can undertake a catalogue data search. The information required for a search is as follows:

- The specific data type.
- Area of Interest - defined by latitude and longitude or country and region.
- The dates of interest.
- Maximum cloud cover acceptable.

Examples of search results are listed after the sensor descriptions for the commonly used data. If a search result lists a suitable image in archive, this can be ordered by NRSC's Data Services Department, typically taking 10-15 working days for delivery. If the data required is not in archive, the satellite can be programmed to acquire it at the next available opportunity.

2.2 SATELLITE NAME: LANDSAT

The Landsat series of satellites and sensors were designed for, as the name implies, land based applications. At present Landsat 5 is in operation carrying both the Thematic Mapper (TM) and Multispectral Scanner (MSS) sensors. Prior to this LANDSATs 1, 2 and 3 carried the MSS sensor and Landsat 4 carried both sensors, but TM data acquisition terminated in 1983 due to power supply problems. Landsat 6 unfortunately crashed on launch but the current Landsat 5 will be replaced by Landsat 7 in 1997.

2.2.1 Sensor Name: LANDSAT Multispectral Scanner (MSS)

Sensor Type: Passive

Data Availability: **Dates:** 1972-1995
Coverage: Continuous over U.K.

Wavebands:
1. 0.5-0.6 µm (green)
2. 0.6-0.7 µm (red)
3. 0.7-0.8 µm (red to near infra-red)
4. 0.8-1.1 µm (near infra-red)

Image Extent: 185 x 185 km

Spatial Resolution: 80 metres

Appropriate Scales: 1:100,000

Repeat Frequency: 16 days

Typical Applications

Water Quality: Suspended sediment distributions, estuarine & coastal.
Flood Defence: Suspended sediment distributions, estuarine & coastal.
Land/water boundary mapping.
Recreation and Conservation: Vegetation studies.
Cultural feature mapping.

Approximate Cost: £500 per scene.

2.2.2 Sensor Name: LANDSAT Thematic Mapper (TM)

Sensor Type: Passive

Data Availability: **Dates:** 1982-1995
Coverage: Continuous over U.K.

Wavebands:
1. 0.45-0.52 µm (visible)
2. 0.52-0.60 µm (visible)
3. 0.63-0.69 µm (visible)
4. 0.76-0.90 µm (near infra-red)
5. 1.55-1.75 µm (infra-red)
6. 10.4-12.5 µm (thermal infra-red)
7. 2.08-2.35 µm (infra-red)

Image Extent:	Full Scene:	185 km x 185 km
	Quarter Scene:	98 km x 98 km
Spatial Resolution:	Bands 1-5 & 7:	30 metres
	Band 6:	120 metres
Appropriate Scales:	Bands 1-5 & 7:	1: 50,000
	Band 6:	1:100,000

Repeat Frequency: 16 days

Typical Applications

Water Quality: Suspended sediment distribution, estuarine and coastal waters.
Chlorophyll concentration.
Pollution studies, colour and thermal.

Water Resources: Geological Mapping
Water body inventories
Hydrogeological studies/river bank erosion studies
Groundwater pollution risk studies.

Flood Defence: Suspended sediment distribution, estuarine and coastal waters.
Land/water boundary mapping.

Fisheries: Thermal mapping of water-bodies.

Recreation and Conservation:	Vegetation mapping Habitat classification Mapping of cultural features		
Approximate Cost:	**Full Scene:**	£3000	
	Quarter Scene:	£2000	

Data Search Details:

Landsat MSS and TM have set paths and rows designated world-wide, so each area of the globe is registered by a path and row number. These path and row details for Landsat 4 and 5 over the U.K. are shown in Figure 2.1. The path is the north-south track and the row depends on the latitude of the scene. Specifying a latitude / longitude for an area of interest allows the appropriate scene or quarter scene to be identified.

A sample search result for Landsat TM or MSS is shown in Figure 2.2. From left to right these values mean:

M - Mission , Landsat 5
TRK - Track, Path Number
FRM- Frame, Row Number
STZ - Station ID, FO-Fucino, KI-Kiruna
SENS - Sensor TM - Thematic Mapper or MSS - Multispectral Scanner
DATE- YYMMDD
CC- Cloud Cover Top Left, Top Right, Bottom Left, Bottom Right quadrants. 0 none 9 high.
ACQ - Amount of frame loss. 0 - none, 9 - > 18 scan lines lost.
VIS - Levels of contrast applied, 0 - good, 9 - poor.
LAT. LONG - Estimated position of scene centre in hundredths of degrees.
ELEV. - Sun Elevation in hundredths of degrees.
AZIM - Sun Azimuth in hundredths of degrees.
NO - Number of scenes found in search.

The percentage of cloud cover is extremely important, it is listed for the whole scene and each quarter. Should the percentage be higher than you would like, a *quick-look* of the image can be provided for a small fee. A quick look is a sub sampled paper print of the image to give an indication of image quality and cloud cover.

An example of a LANDSAT scene is shown in Figure 2.3.

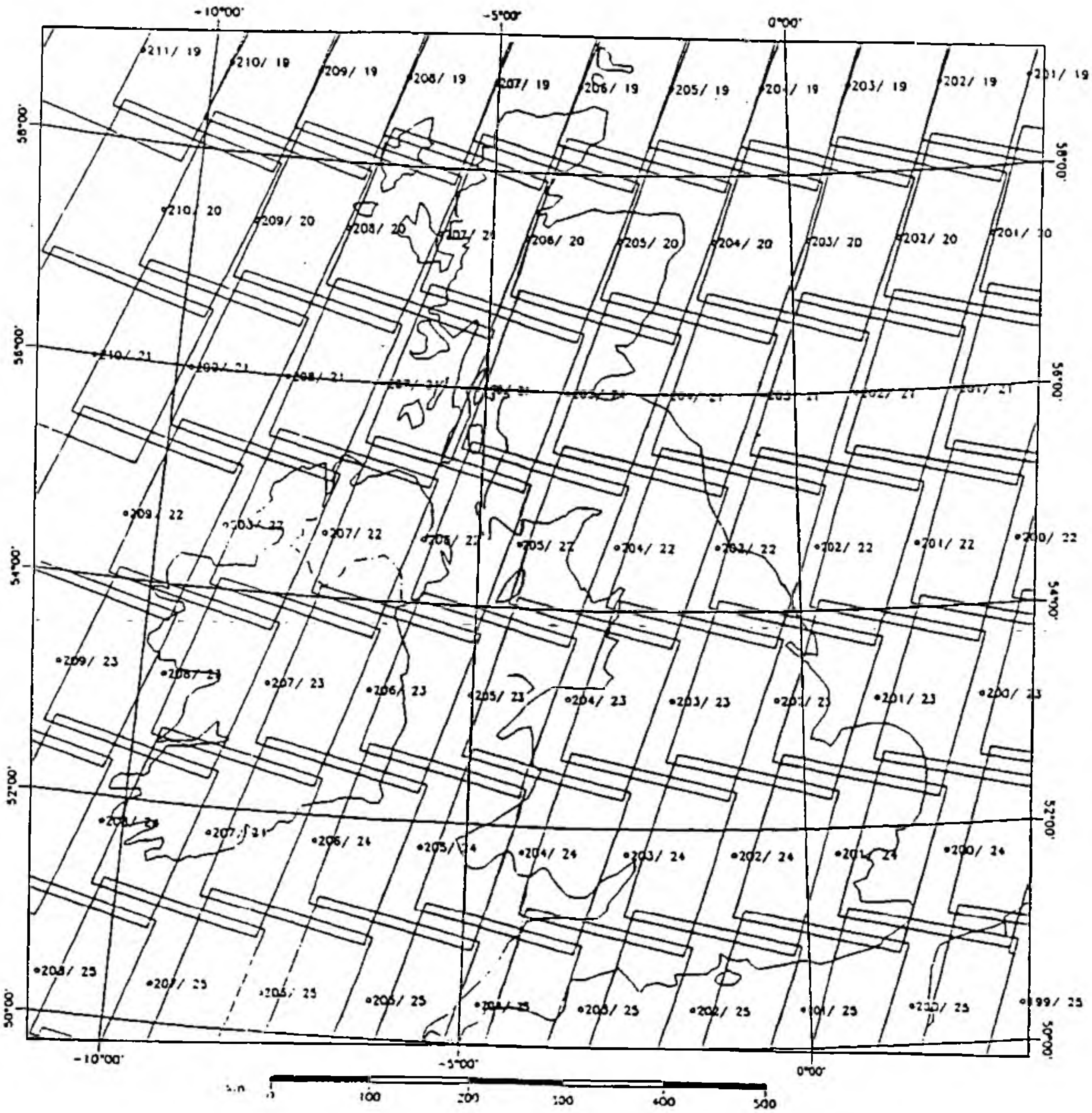


Figure 2.1 UK Paths and Rows for Landsats 4 & 5

HUMBER LANDSAT TM &MSS COVERAGE 1994-1995

MIS	TRK	FRM	STZ	SENS	DATE	CLOUD-COV	ACQ-VIS	LAT.	LONG.	ELEV.	AZIM.	NO.
5	202	22	FO	T.M.	940125	1 1 3 3	0 3	5451	23	1268	15283	1
5	202	22	FO	T.M.	940226	- - - -	0 3	5451	19	2241	14944	2
5	202	22	KI	T.M.	940821	1 0 2 1	0 3	5451	16	4261	14304	3
5	202	22	KI	T.M.	950317	- - - -	0 3	5451	14	2881	14520	4
5	203	21	FO	T.M.	940406	1 3 3 1	0 3	5591	-65	3660	14802	5
5	204	21	FO	T.M.	940413	3 1 2 3	0 3	5591	-219	3921	14755	6
5	204	21	FO	T.M.	940803	- - - -	0 3	5591	-219	4652	14114	7

.... END OF LIST ....

Figure 2.2 An Example Landsat Search Result

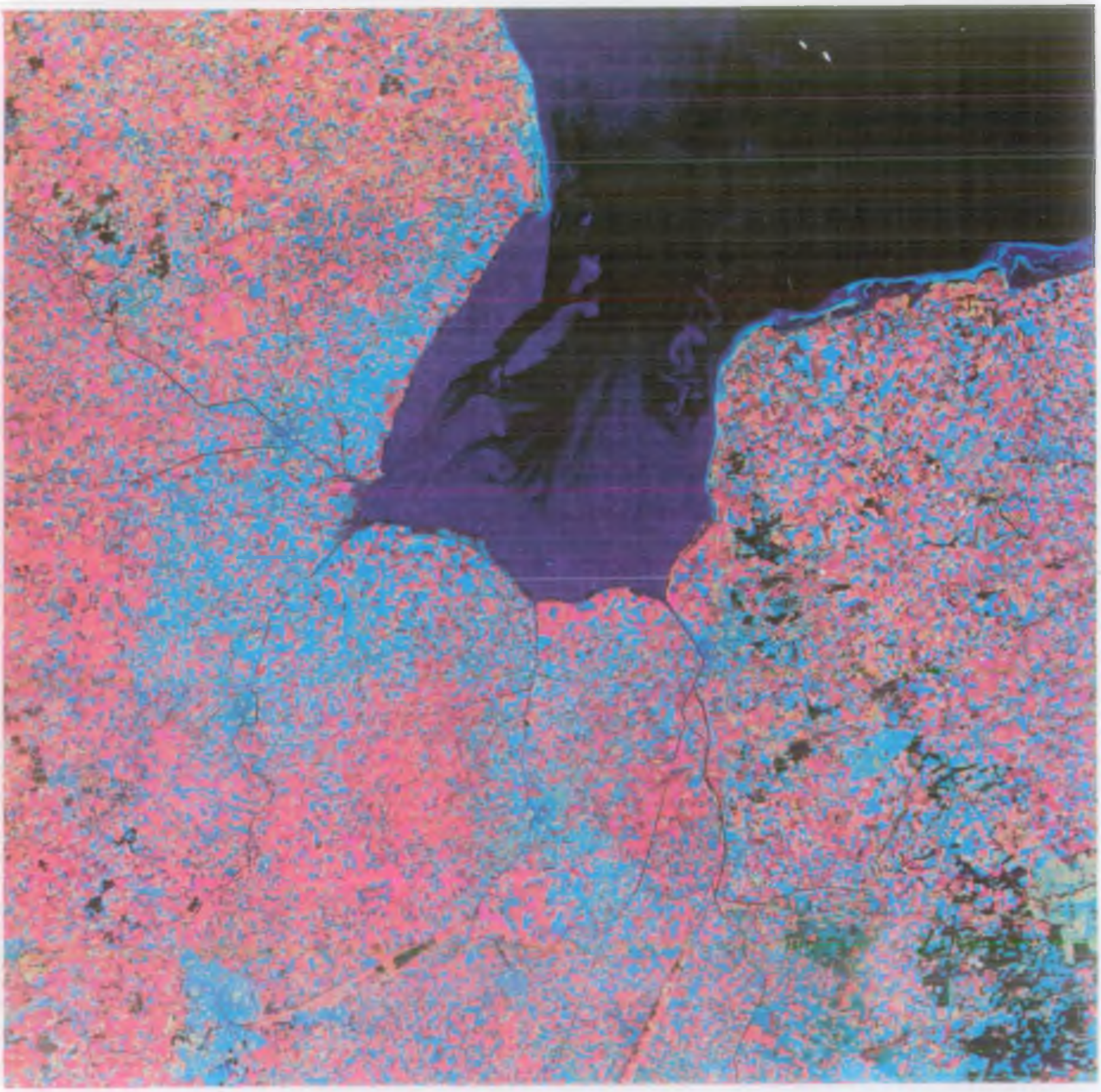


Figure 2.3 An Example Landsat Scene - The Wash

2.3 SATELLITE NAME: SATELLITE POUR OBSERVATION DE LA TERRE - SPOT

SPOT are a series of French remote sensing satellites designed to provide high resolution images of the earth for land-use and coastal zone studies. First launched in 1986, three satellites are in operation so far. The second generation of satellites, SPOT 4 & 5, are due to be launched in 1996/7 and 2000 respectively. These will have a sensor with an extra waveband in the mid infra-red.

2.3.1 Sensor Name: High Resolution Visible Detectors (HRV) (two for stereo-pairs)

Sensor Type: Passive

Data Availability: **Dates:** 1986-1995
Coverage: Continuous over U.K.

Wavebands: **Panchromatic (PAN):** 1. 0.51-0.73 µm (visible & near infra-red)

Multispectral (XS):
1. 0.50-0.59 µm (green)
2. 0.61-0.68 µm (red)
3. 0.79-0.89 µm (near infra-red)

Image Extent: **Panchromatic:** 60km x 60 km
Multispectral: 60km x 60 km

Spatial Resolution: **Panchromatic:** 10 metres
Multispectral: 20 metres

Appropriate Scales: **Panchromatic:** 1:25,000
Multispectral: 1:50,000/1:25,000

Repeat Frequency: 26 days, but can be programmed to obtain more frequent acquisition.

Approximate Cost: Panchromatic:
£2,000 per scene
£3,000 for a stereo-pair of images.

Approximate Cost: Multispectral
£1,600 per scene
£2,400 for a stereo-pair of images

Typical Applications - Panchromatic Imagery

Water Resources: Water body inventories
Hydrogeology.
Flood Defence: Coastal mapping & change detection
Production of digital elevation models for topographic analysis.
Recreation and Conservation: Land-use mapping.
Flood damage analysis.

Typical Applications - Multispectral Imagery

Water Quality: Qualitative water quality studies
Pollution monitoring.
Water Resources: Water body inventories
Hydrogeological studies/river bank erosion studies
Groundwater pollution risk studies.
Flood Defence: Coastal mapping & change detection
Production of digital elevation models for topographic analysis.
Recreation and Conservation: Land-use mapping
Vegetation mapping
Habitat classification
Flood damage analysis

Data Search Details:

NRSC has an on-line system to search available catalogues for SPOT data, both Panchromatic and Multispectral. Again SPOT images are referenced by path and row, in this instance these are called K and J numbers. Our data services team will search for scenes by geographic latitude and longitude or path and row.

If the required scene was acquired after 1991 it should have an appropriate quick look associated with it. This quick-look can be printed out to produce hard copy. An example of a Panchromatic black and white quick look is shown in Figure 2.4. A quick-look of a Multispectral scene is shown in Figure 2.5. The panchromatic quick-look is sub sampled by 12 and the multispectral by 6 which means that only every twelfth or sixth scan line is shown respectively. If the scene was acquired prior to 1991 a quick-look can be requested from the distributors.

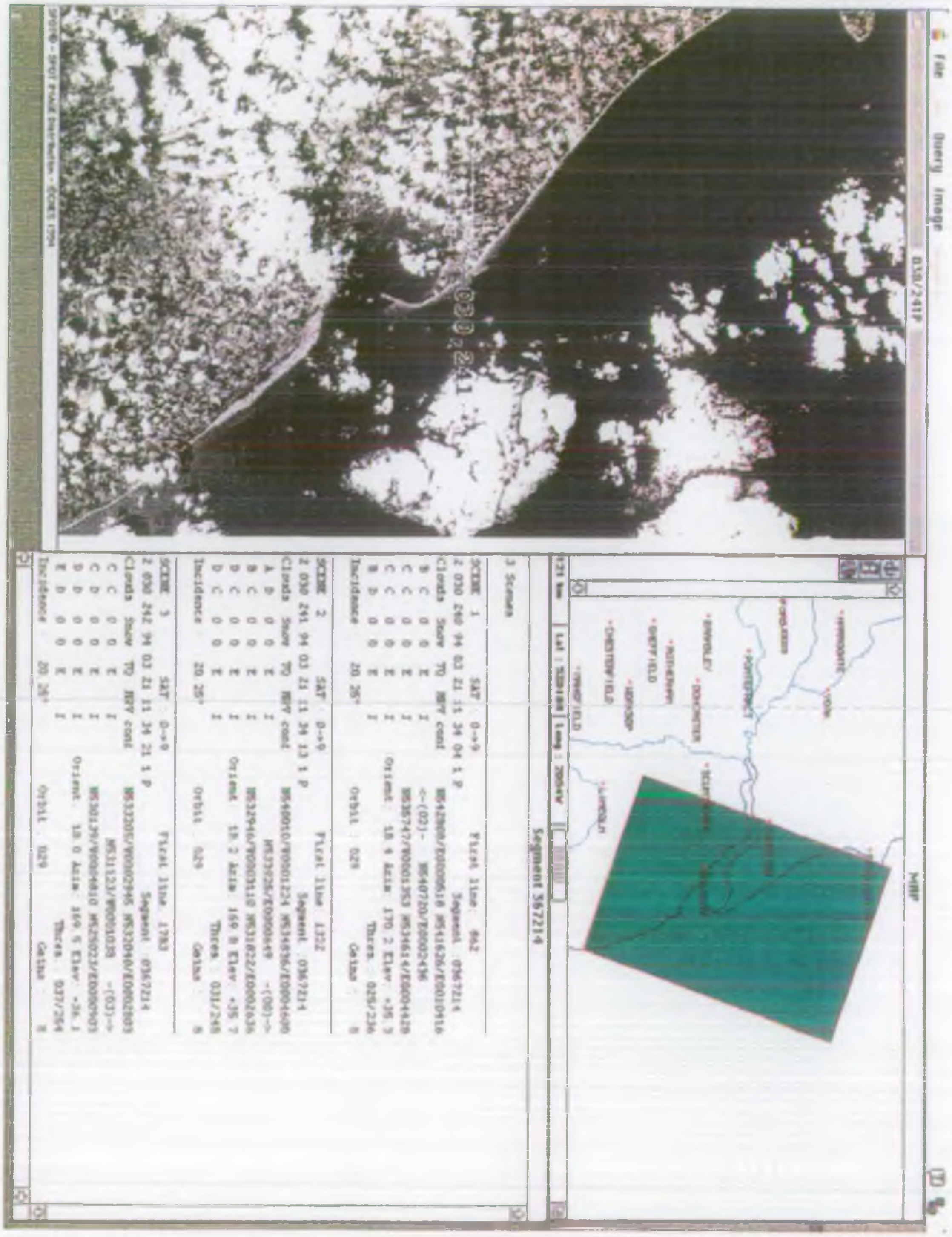


Figure 2.4 SPOT Panchromatic (PAN) Data Quick-Look

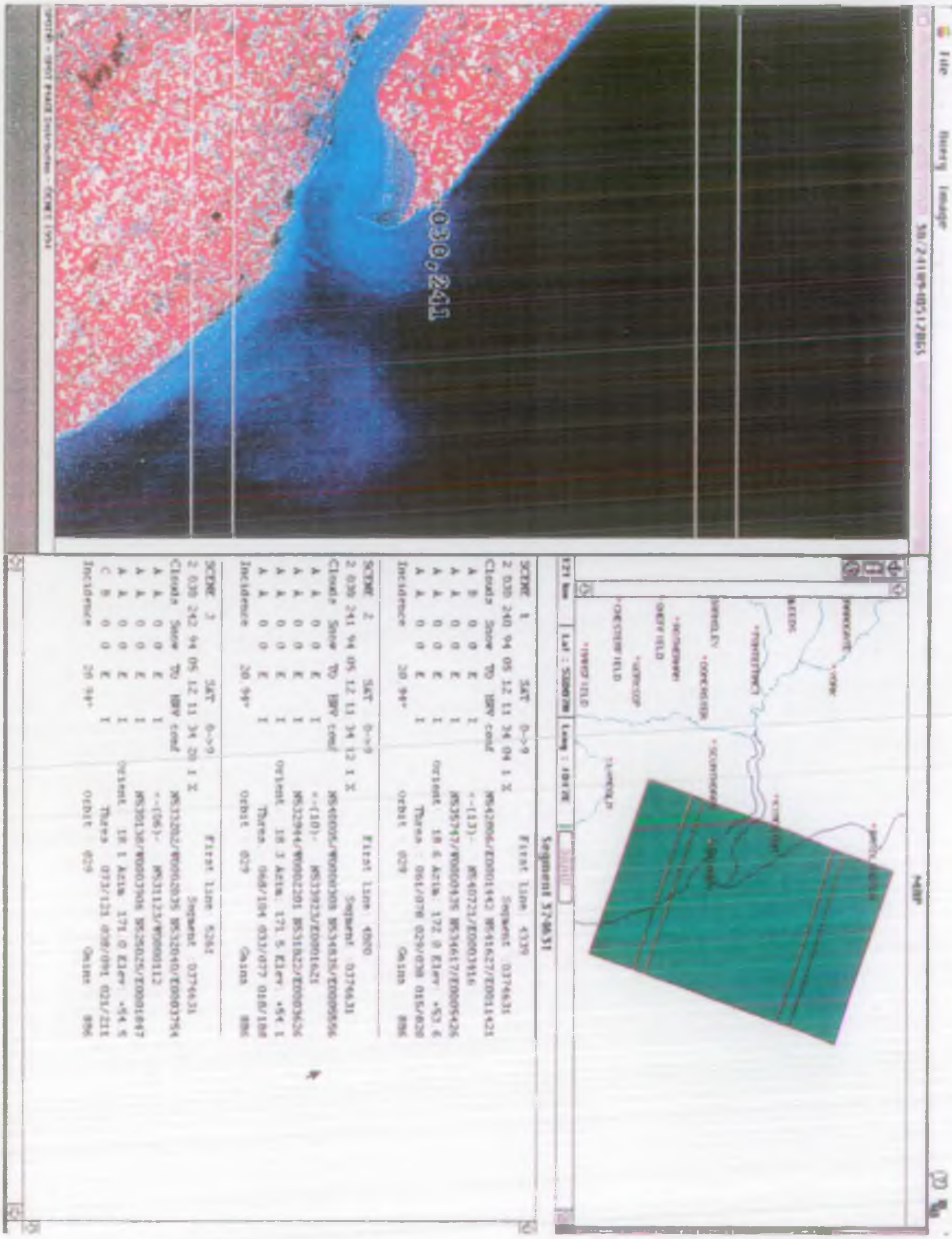


Figure 2.5 SPOT Multispectral (XS) Data Quick-Look

A sample search result for both Panchromatic and Multispectral data is shown in Figure 2.6. From left to right these values mean:

Top Row

Scene ID 3 033-242 94/09/01 11:38:00 2X

3 - Satellite number SPOT 3
033 - K number
242 - J number
94/09/01 - Date of Acquisition YY/MM/DD
11:38:00 - Time of Acquisition (GMT)
2 X - HRV instrument number and acquisition mode, X multispectral; P panchromatic.

SAT - (0-9) Completeness of Scene 0-9 whole scene.

NW - CORNER - north west of the scene in degrees, minutes, seconds of latitude/longitude.
NE - CORNER - north east of the scene in degrees, minutes, seconds of latitude/longitude.

Middle Row

CLOUD - After 1991 Cloud cover assessment based on segmenting a scene into eight sections.
If the list read ABCDEABC

A	B
C	D
E	A
B	C

A - 0% **B** - 1% - 10% **C** - 11% - 25% **D** - 26% - 75% **E** - 76% - 100%

CLOUD - Pre 1991 Cloud cover assessment based on dividing scene into 4 sections.
If listed as ABCD

A	B
C	D

TQ - Technical Quality, E - Excellent, P - Poor, G - Good, U - Unusable.
ORB - Orbit number
INCID - Angle between look direction at the scene centre and a line perpendicular to the reference ellipsoid. Angle of Incidence in degrees and tenths of degrees.

HUMBER SPOT P & XS COVERAGE 1994-1995

```
VIEW :   940301 - 950324  CC:C   Ms:*   Hrv:*   incid1:-31.06
                   Conf:*  sn:*   Tq:U   Sat:*   incid2:+31.06
=========================================================================
SCENE ID(S KJ DATE TIME I MS)     SAT        NW-CORNER           NE-CORNER
 CLOUD    TQ   ORB INCID ORIEN                         CENTER              Dkm
 SNOW     CONF GAIN V-ANG. AZIM/SITE          SW-CORNER           SE-CORNER
======   000013   scenes ================= Page : 000001/000001      ======
3 030-241 94/03/10 11:03:40 1 P (0-9)  N535833/W0002059  N535118/E0003726
BBBBDCED EEEE  199 -17.2 011.9                  N533922/E0000152       -06
00000000 I     8   -15.2 160.6/+30.1   N532716/W0003358  N532006/E0002345

2 030-241 94/03/21 11:34:13 1 P (0-9)  N540010/W0001224  N534836/E0004559
ADBCDCDC EEEE  029 +20.3 018.2                  N533924/E0000649       -01
00000000 I     8   +17.8 169.8/+35.7   N532946/W0003111  N531822/E0002635

[illegible] 030-241 94/03/26 11:38:04 2 P (0-9)  N540040/W0000745  N534747/E0005402
[illegible] EEEE  100 +24.8 019.1                  N533923/E0001239       +06
00000000 I     7   +21.8 171.4/+37.8   N533026/W0002717  N531744/E0003351

2 030-241 94/05/12 11:34:12 1 X (0-9)  N540005/W0000308  N534835/E0005555
AAAAAAAA EEEE  029 +20.9 018.3                  N533923/E0001620       +10
00000000 I     886 +18.4 171.5/+54.1   N532944/W0002201  N531823/E0003625

2 030-241 94/06/13 11:18:45 1 X (0-9)  N535856/W0001339  N535029/E0003912
BACABAAB EEEE  114 +01.9 015.1                  N533923/E0000435       -03
00000000 I     886  +1.6 161.9/+58.6   N532802/W0002934  N531942/E0002239

3 030-241 94/06/15 11:38:12 1 X (0-9)  N540029/W0001348  N534759/E0004754
CBCCCBCB EEEE  100 +24.4 019.0                  N533922/E0000636       -01
00000000 T     655 +21.4 170.3/+59.4   N533014/W0003315  N531754/E0002748

2 030-241 94/06/28 11:30:15 1 X (0-9)  N535941/W0000846  N534915/E0004728
[illegible]CBBABA EEEE  327 +16.1 017.5                  N533924/E0000948       +02
00000000 T     886 +14.2 165.7/+59.1   N532909/W0002653  N531852/E0002845

3 030-241 94/07/29 10:51:43 2 X (0-9)  N535839/W0001959  N535126/E0004939
BACBCDED EEEE  355 -29.3 009.7                  N533922/E0000955       +03
```

Figure 2.6 Example SPOT PAN & XS Search Result

ORIEN - Angle through which the image centreline direction must be rotated in order to align with true east at the centre of the raw image. Image orientation is expressed in degrees and tenths of degrees.
CENTER - Geographic coordinates of the centre of the raw scene in degrees, minutes and seconds of longitude/latitude.
Dkm - Scene centre to KJ node in kilometres.

Bottom Line

SNOW - Snow cover assessment, segmented into eight sections and given the numbers 1 or 0 to describe the amount of snow present in each section.
For example the sequence of 0110001.

0	1
1	0
0	0
1	1

CONF - Configuration of the sensor.
I - Independent, each sensor operating independently in each spectral mode XS and Pan.
T - Twin, The pair of HRV instruments is configured in such a way that the instrument's acquisition strips overlap slightly, by means of the particular orientation of the two strips selection mirrors.
D - Dual - Only one of the instruments is used in P+XS mode and it performs acquisitions two acquisitions in two spectral modes (XS and P). The other instrument is inoperative.

GAIN - gain value for each spectral band. Relates to the spectral response of the instrument at the time of receiving the data. The values represent the mean values of measurements corrected for methodical effects, in particular air-vacuum transition. Individual detectors will give a slightly different response about this mean value.

V-ANG - Viewing angle. Angle made, in HRV object space, between the geocentric direction and the vector to the centre of the HRV field of view. Acquisition angle is expressed in decimal degrees.

AZIM/SITE - Sun Azimuth and elevation angles at the scene centre at the moment the pixel is acquired, as indicated in the 'viewing date' field.

SW-CORNER - south west of the scene in degrees, minutes, seconds of latitude/longitude.
SE - CORNER - south east of the scene in degrees, minutes, seconds of latitude/longitude.

2.4 SATELLITE NAME: NOAA SERIES

A series of American weather satellites evolved from experimental and operational satellites beginning in 1978. NOAA 12 and 14 have recently been launched.

2.4.1 Sensor Name: Advanced Very High Resolution Radiometer (AVHRR)

Sensor Type: Passive

Data Availability: **Dates:** 1970 - 1995 and onward to next century
Coverage: Continuous U.K. Coverage

Wavebands:
1. 0.58 - 0.68 µm (visible)
2. 0.725-1.10 µm (near infra-red)
3. 3.55 - 3.93 µm (middle infra-red)
4. 10.3 -11.3 µm (thermal infra-red)
5. 10.3 -12.5 µm (thermal infra-red)

Image Extent: 3,000 km x 3,000 km - 25,000 km x 6,000 km

Spatial Resolution: **Global Area Coverage:** 4.0 kilometres
Local Area Coverage: 1.1 kilometres

Appropriate Scales: **Global Area Coverage:** 1:1,000,000
Local Area Coverage: 1:250,000 - 1:500,000

Repeat Frequency: With two satellites acquiring imagery simultaneously, four overpasses per day are possible.

Typical Applications

Water Quality: Thermal pollution monitoring.
Mixing Zones
Large scale circulation studies
Water Resources: Meteorology
Soil moisture studies
Recreation and Conservation: Normalised vegetation indices (NDVI) - measure of plant health & change over time.
Agricultural monitoring, commodities forecasting.

Approximate Cost: £75 per scene

Data Search Details:

Should you require AVHRR imagery, again NRSC can provide a search service. An example search result is shown in Figure 2.7 and from left to right the values mean:

AL11010492080106 - Unique scene identifier
DATE ACQUIRED - DD/MM/YYYY

MICROFRAME NUMBER - The quick looks are sometimes be stored on microfiche.

NORTHWEST LATITUDE	N/S Decimal Degrees
NORTHWEST LONGITUDE	E/W Decimal Degrees
SOUTHEAST LATITUDE	N/S Decimal Degrees
SOUTHEAST LONGITUDE	E/W Decimal Degrees

An example quick look of an AVHRR scene is shown in Figure 2.8. A mosaic of enhanced AVHRR colour composite is shown in Figure 2.9.

22DEC94 11:54 FROM 62009777 S111781L TO 01144252370824 VIA AT&T EASYLINK PAGE 13 OF 13

Date: 1994/12/22
Time: 10:47

Global Land Information System
U.S. Geological Survey
EROS DATA CENTER
Sioux Falls, SD 57198
AVHRR INVENTORY

Report: OPTION 2
Page : 12 of 12

ENTITY ID	BRWS	AREA IND	DATE ACQUIRED	NORTHWEST LATITUDE	NORTHWEST LONGITUDE	SOUTHEAST LATITUDE	SOUTHEAST LONGITUDE
AL11010492080106	Y	S	04/01/1992	N18.20	E082.24	S10.14	E118.16
AL11010492080458	Y	S	04/01/1992	N35.55	E074.38	N02.46	E114.52
AL11010392081302	Y	S	03/01/1992	N18.22	E079.22	S10.09	E115.15
AL11010392081652	Y	S	03/01/1992	N35.54	E071.38	N02.49	E111.52
AL11010292082649	Y	S	02/01/1992	N35.51	E068.39	N02.53	E108.51

*** End Of Report ***

Figure 2.7 AVHRR Search Result

SHARK AVHRR

28 APR 1993	NOAA-11	Archive ID: DLD93116S11B
Start: 14:34:37	ASCENDING	Scene ID: DL119304281436
Stop: 14:38:37		Acquired: DLR

European Space Agency / Earthnet Programme ...
ESRIN, Via Galileo Galilei, 00044 Frascati, Italy
Telephone: +39 (6) 941801 Telex: 610637 ...
Fax: +39 (6) 94180361

Percentage of each cover type:			
sea	27	cloud	38
sunglint	1	snow/ice	0
land	31	unclass.	3

Figure 2.8 AVHRR Quick Look

Figure 2.9 AVHRR Colour Composite of Europe

2.5 SATELLITE NAME: RESOURCE-F

A Russian series of satellites that have high resolution sensors on board. A limited number of U.K. images are available.

2.5.1 Sensor Name: KFA 1000

Sensor Type: Passive

Data Availability: **Dates:** 1981-1990
Coverage: Limited over U.K.

Wavebands: 1. 0.57-0.68 µm (visible)
2. 0.67-0.81 µm (visible - near infra-red)

Image Extent: 80 km x 80 km

Spatial Resolution: 2-5 metres

Appropriate Scales: 1:10,000

Repeat Frequency: Archive only

Typical Applications

Water Quality: Qualitative pollution monitoring.

Water Resources: Water body inventories

Recreation and Conservation: Large scale mapping.

Approximate Cost: £2,000 per scene

2.5.2 Sensor Name: **MK4**

Sensor Type: Passive

Data Availability: **Dates:** 1990-1993
Coverage: Limited over U.K.

Wavebands:
1. 0.635-0.69 μm (visible)
2. 0.81-0.9 μm (near infra-red)
3. 0.515-0.565 μm (visible)
4. 0.46-0.505μm (visible)
5. 0.58-0.8 μm (visible - near infra-red)
6. 0.4-0.7 μm (visible)

Image Extent: 117km x 117km - 173km x 173km (variable)

Spatial Resolution: 8 - 10 metres

Appropriate Scales: 1:25,000

Repeat Frequency: Archive only

Typical Applications

Water Quality: Qualitative pollution monitoring.

Water Resources: Water body inventories.

Recreation and Conservation: Large scale mapping.

Approximate Cost: £2,000 per scene

2.5.3 Sensor Name: **KATE-200**

Sensor Type: Passive

Data Availability: **Dates:** 1981-1990
Coverage: Limited over U.K.

Wavebands:
1. 0.5-0.6 μm (visible)
2. 0.6-0.7 μm (visible)
3. 0.7-0.85 μm (near infra-red)

Image Extent: 216km x 216km - 243km x243km (variable)

Spatial Resolution: 15-20 metres

Appropriate Scales: 1:25,000/1:50,000

Repeat Frequency: Archive only

Typical Applications

Water Quality: Qualitative pollution monitoring.

Water Resources: Water body inventories.

Recreation and Conservation: Land use mapping.

Approximate Cost: £1,000 per scene

2.6 SATELLITE NAME: European Remote Sensing Satellite (ERS-1)

The European Space Agency's first remote sensing satellite, designed to provide images in the microwave spectrum. This radar payload allows observations through cloud and darkness.

2.6.1 Sensor Name: ERS-1 Active Microwave Instrument

Sensor Type: Active

Data Availability: **Dates:** 1991-1995
Coverage: Continuous over U.K.

Frequency: 5.3 GHz (C-band)

Image Extent: **Synthetic Aperture Radar Image Mode:**100 km x 100 km
Synthetic Aperture Radar Wave Mode: 5 km x 5 km
Wind Scatterometer: Global coverage

Spatial Resolution: **SAR Image Mode:**12.5 metres
Wind Scatterometer: 47 kilometres

Appropriate Scales: **SAR Image Mode:**1:50,000

Repeat Frequency: 168 days, 35 days or 3 days

Typical Applications - SAR Image Mode

Water Quality: Oil slick mapping.
Currents and wave studies.
Water Resources: Water body change detection.
Flood Defence: Currents and wave studies.
Conservation: Forestry mapping
Flood detection / monitoring
Land cover classification

Approximate Cost: £700 per scene.

Typical Applications - SAR Wave Mode

Coastal Engineering, wave refraction studies.

Approximate Cost: Global coverage, monthly £350.
Typical Applications - Wind Scatterometer

Wind speed and direction.
Coastal process studies.
Pollution monitoring.

Approximate Cost: Global Coverage Monthly - £270
Global Coverage Yearly - £3,000

Data Search Details:

NRSC has an on-line search facility to access ERS-1 data. A search result is shown in Figures 2.10 and 2.11. The first shows the scene orbits and frames and a visual location of the scenes, the second gives details of each Synthetic Aperture Radar scene and their corner co-ordinates.

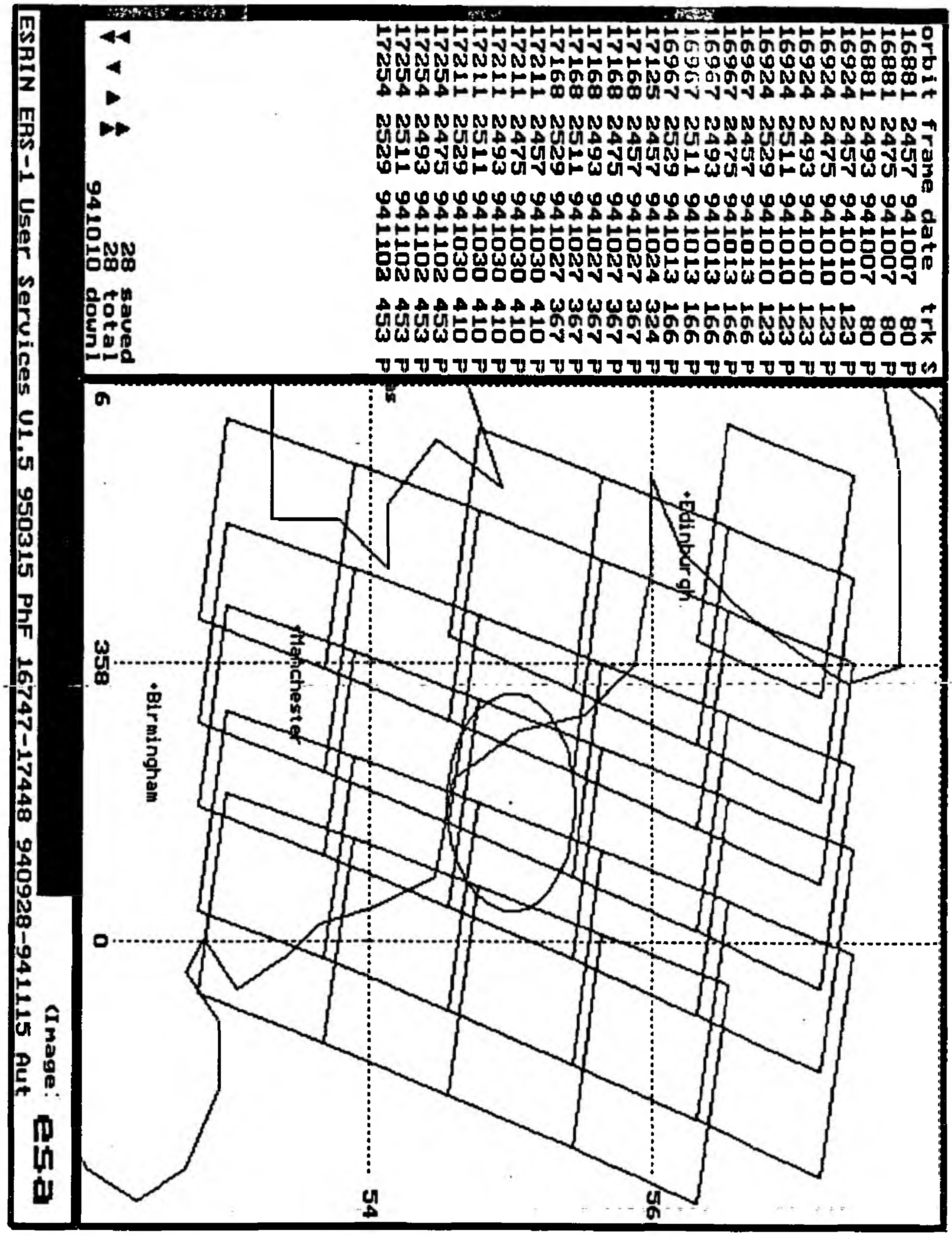


Figure 2.10 ERS-1 Synthetic Aperture Radar Search Result - Visual

orbit	frame	date	trk	S	latit	longit	latit	longit	latit	longit	latit	longit
16881	2457	941007	80	P	57°24	-2°36	57°11	-1° 0	56°18	-1°24	56°31	-2°58
16881	2475	941007	80	P	56°31	-2°58	56°18	-1°24	55°26	-1°48	55°38	-3°20
16881	2493	941007	80	P	55°38	-3°20	55°26	-1°48	54°33	-2°11	54°45	-3°40
16924	2457	941010	123	P	57°24	-1°15	57°11	0°20	56°18	-0° 4	56°31	-1°37
16924	2475	941010	123	P	56°31	-1°37	56°18	-0° 4	55°26	-0°27	55°38	-1°59
16924	2493	941010	123	P	55°38	-1°59	55°26	-0°27	54°33	-0°50	54°45	-2°20
16924	2511	941010	123	P	54°45	-2°20	54°33	-0°50	53°40	-1°12	53°52	-2°40
16924	2529	941010	123	P	53°52	-2°40	53°40	-1°12	52°47	-1°33	52°59	-2°59
16967	2457	941013	166	P	57°24	0° 4	57°11	1°40	56°18	1°16	56°31	-0°17
16967	2475	941013	166	P	56°31	-0°17	56°18	1°16	55°26	0°52	55°38	-0°38
16967	2493	941013	166	P	55°38	-0°38	55°26	0°52	54°33	0°30	54°45	-0°59
16967	2511	941013	166	P	54°45	-0°59	54°33	0°30	53°40	0° 8	53°52	-1°19
16967	2529	941013	166	P	53°52	-1°19	53°40	0° 8	52°47	-0°13	52°59	-1°39
17125	2457	941024	324	P	57°24	-3°21	57°11	-1°45	56°18	-2° 9	56°31	-3°43
17168	2457	941027	367	P	57°24	-2° 0	57°11	-0°24	56°18	-0°49	56°31	-2°22
17168	2475	941027	367	P	56°31	-2°22	56°18	-0°49	55°26	-1°12	55°38	-2°44
17168	2493	941027	367	P	55°38	-2°44	55°26	-1°12	54°33	-1°35	54°45	-3° 4
17168	2511	941027	367	P	54°45	-3° 4	54°33	-1°35	53°40	-1°57	53°52	-3°25
17168	2529	941027	367	P	53°52	-3°25	53°40	-1°57	52°47	-2°18	52°59	-3°44
17211	2457	941030	410	P	57°24	-0°39	57°11	0°55	56°18	0°31	56°31	-1° 2
17211	2475	941030	410	P	56°31	-1° 2	56°18	0°31	55°26	0° 7	55°38	-1°23
17211	2493	941030	410	P	55°38	-1°23	55°26	0° 7	54°33	-0°14	54°45	-1°44
17211	2511	941030	410	P	54°45	-1°44	54°33	-0°14	53°40	-0°36	53°52	-2° 4
17211	2529	941030	410	P	53°52	-2° 4	53°40	-0°36	52°47	-0°57	52°59	-2°23
17254	2475	941102	453	P	56°31	0°18	56°18	1°52	55°26	1°28	55°38	-0° 2
17254	2493	941102	453	P	55°38	-0° 2	55°26	1°28	54°33	1° 5	54°45	-0°23
17254	2511	941102	453	P	54°45	-0°23	54°33	1° 5	53°40	0°43	53°52	-0°43
17254	2529	941102	453	P	53°52	-0°43	53°40	0°43	52°47	0°22	52°59	-1° 3

▼▼ ▼ ▲ ▲▲ 28 saved
28 total
941010 downl

NOMINAL COORDINATES OF FRAMES (Degrees-minutes)

(Image: esa

ESRIN ERS-1 User Services V1.5 950315 PhF 16747-17448 940928-941115 Aut

Figure 2.11 ERS-1 Synthetic Aperture Radar Search Result - Corner Coordinates

Figure 2.12 ERS-1 Synthetic Aperture Radar Image of the Isleof Wight. The long dark streak in the south is oil pollution, possibly from vessel tank washing. ©ESA, 1991.

2.6.2	**Sensor Name:**	**ERS-1 Radar Altimeter**
	Sensor Type:	Active
	Data Availability:	**Dates:** 1991-1995 **Coverage:** Continuous over U.K.
	Frequency:	13.8 GHz (Ku-band)
	Image Extent:	500 km x continuous strip
	Spatial Resolution:	Accuracy - Wave Height +/- 0.5 metres Altitude 0.1 metres
	Repeat Frequency:	35 days (3 days)
	Typical Applications	
	Water Quality:	Currents and wave studies
	Flood Defence:	Wave height Wind speed Significant wave height
	Approximate Cost:	Global Coverage, monthly £270. Global Coverage, yearly basis £3000.

2.6.3	**Sensor Name:**	**ERS-1 Along Track Scanning Radiometer (ATSR)**
	Sensor Type:	Passive
	Data Availability:	**Dates:** 1991-1995 **Coverage:** Continuous over U.K.
	Comprises:	**Infra-red Radiometer (IRR) (Passive)** **Microwave Sounder (MWS) (Passive)**
	Image Extent:	500 x 500 km
	Spatial Resolution:	1 kilometre
	Repeat Frequency:	35 days (3 days)

Typical Applications

Water Quality: Thermal Pollution Monitoring, mixing zones.
Large scale circulation patterns

Approximate Cost: £100

Data Search Details: ATSR has only just become commercially available so search details cannot be provided yet. It is predicted that a cloud cover estimate will be available for the whole image and for each of 100 squares.

See Section 2.7 for description of the improved ATSR-2.

2.7 ERS-2

The ERS-1 spacecraft was originally expected to operate until mid-1993. However, it continues to operate today, exceedig its design specifications. On 21 April 1995, ERS-2 , the next spacecraft in the series, was successfully launched. ERS-2 is designed primarily as a "continuation" spacecraft from ERS-1, should the first spacecraft now fail. Providing ERS-1 remains operational, however, it is currently planned to operate the two spacecraft in a tandem mode, providing increased coverage.

To facilitate this continuity of data, many of the ERS-2 instruments, such as the active microwave and radar packages, are the same as those on ERS-1. The ATSR instrument design has, however, been upgraded; the improved sensor installed on ERS-2 is designated ATSR-2. Another upgraded version of the ATSR is planned for the ENVISAT mission in 1998; this is currently referred to as the AATSR (Advanced ATSR) to avoid confusion with the ERS-2 instrument.

ERS-2 is currently undergoing a commissioning phase. Data from ERS-2 instruments should become available later in 1995. Both ATSR and ATSR-2 remain essentially experimental instruments rather than operational ones.

The ATSR-2 is basically the ATSR design with a number of "add - on" features, notably additional spectral bands in the visible, near infra-red and thermal regions. These have been selected with a number of specific applications in mind, including derivation of vegetation indices, cloud temperature and aerosol studies, forest fire monitoring and sea surface temperature measurement. Parametres such as radiometric resolution, field of view and "dual look" capability remain the same to ensure continuity of data quality between the two instruments.

Section No.3

Airborne Sensors

3.1 INTRODUCTION

Airborne sensors are most commonly carried on light aircraft. These are of a similar nature to spaceborne sensors, being either passive or active. Their main advantages are the increased scale at which the information is acquired, e.g. 1:10,000, and problems of cloud cover are generally eliminated. Also included in this section are laser sensors and imaging spectrometers. Laser sensors include radar-like instruments such as LIDAR, and laser fluorosensors. At present, these are generally only deployed in aircraft, although satellite-borne imaging spectrometers are being proposed for the next few years.

A number of UK companies undertake airborne surveys and the National Centre for Instrumentation and Marine Surveillance, NRA South Western Region, carries out extensive airborne campaigns often combining sorties with ship surveys. As part of its remit to survey the coastal region out to the 3 km limit, NCIMS conducts a data collection campaign around the entire coast of England and Wales four times a year. This includes the collection of CASI data which is archived at NRA South Western Region in Bath. Details of the CASI system follow in the next section.

Also included in this airborne section is the use of aerial photography and NCIMS maintains an archive of coastal air photographs. The traditional methods of mapping and interpretation from aerial photography using stereoscopic viewers have recently been superseded by digital methods. The photographs can be scanned into the system and referenced to a map projection in a similar manner to satellite imagery. The benefits of digital photography include the ability to overlay map information, change detection analysis and data storage capability.

3.2 SENSOR NAME: Compact Airborne Spectrographic Imager (CASI)

3.2.1 System Description

The CASI is designed to provide a flexible spectrographic imaging system, which is easy to transport and straightforward to install and operate in small aircraft. The system is a "pushbroom" configuration, i.e. the full swath width is imaged instantaneously, in a large number of spectral wavebands (up to 288) covering the visible and NIR regions of the spectrum between 0.430 µm and 0.870 µm, at 0.0018 µm intervals. This can be used to construct "hyperspectral" image datasets for detailed studies of the spectral characteristics of ground or water targets.

Light reflected from the ground is received by the CASI optical system and focused onto a diffraction grating. This has an effect analogous to a glass prism, splitting the light up into its component wavelengths. The light then falls onto a two dimensional array of Charge Coupled Devices (CCD's) which electronically measure the amount of light falling on them.

The array consists of 288 rows of detectors, with each row containing 512 individual CCD units. The rows are positioned with respect to the diffraction grating such that each row "sees" a different wavelength of light. The 512 detectors in each row image a line on the ground, enabling a swath width 512 pixels across to be imaged on the ground. As the aircraft moves over the ground, the CCD array is repeatedly read out, and a two dimensional image is slowly built up. The along-track spatial resolution if the image is governed by the speed of the aircraft and the frame rate at which the CCD array is read out. The across-track spatial resolution is governed by the flying altitude. This configuration allows all the spectral bands to be automatically co-registered, and the absence of any moving parts in the system makes for greater flexibility and ease of maintenance.

The CASI instrument is operated in one of four modes:

- **Spatial Mode:** All 512 swath pixels are recorded, in up to 19 wavebands, the wavelength and width of which can be interactively specified by the operator.
- **Spectral Mode:** Data from all 288 spectral bands are recorded, but from only 39 pixels across the swath (so-called "push rake" configuration).
- **Enhanced Spectral Mode:** Data can be acquired over approximately 300 pixels in up to 74 channels.
- **Full Frame Mode:** The entire swath of 512 pixels is imaged in all 288 spectral wavebands. (only used for calibration and testing)

Data are recorded directly onto 8mm Exabyte cassette. Operating software is also installed in the system control unit, enabling immediate viewing and playback of acquired data, and data can be automatically corrected, both radiometrically and geometrically, as they are acquired.

Geometric correction is achieved through the use of a vertical gyroscope to keep track of the aircraft's roll and pitch motion, and a Global Positioning System (GPS) automatically records the position of the aircraft. Radiometric correction can be performed both through preflight calibration constants, and using an "add on" Incident Light Sensor (ILS) to measure the downwelling radiance at the aircraft. This information in turn can be used to directly calibrate the scene data in terms of spectral reflectance values, rather than absolute radiance values. The CASI instrument is used by NCIMS as part of the national coastal baseline survey of England and Wales. Further details of this operation are given in Section 6.2.2.

3.2.2 CASI System Summary - See Plates for Examples

Sensor Type: Passive

Wavebands: 288 bands in the visible and near infra-red, from 0.418 - 0.926 µm.
Spatial Mode: Up to 19 bands with selectable width and location.
Spectral Mode: Spectra covering the whole range are recorded.

Image Extent: 5.2 km swath width at 10,000 feet altitude.

Spatial Resolution: 1 - 10 metres depending on altitude

Appropriate Scales: 1:10,000

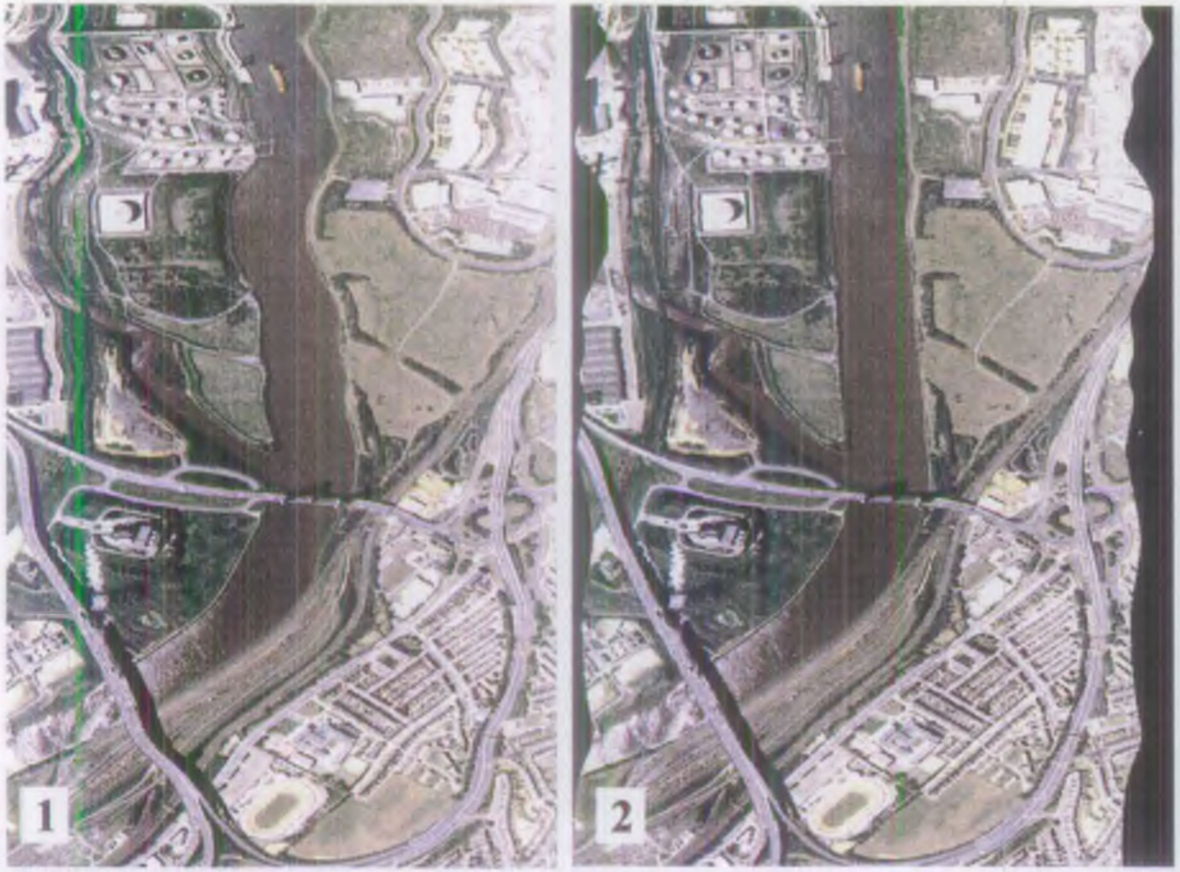
Typical Applications

Water Quality: Suspended sediment studies.
Chlorophyll concentration mapping/ mixing zone studies
Pollution monitoring.

Water Resources: Water body mapping.

Flood Defence: Coastal inventories.

Recreation and Conservation: Vegetation mapping/Species mapping.
Habitat classification.



True colour CASI data. River Tees, Middlesborough.
Date: 14 June 1995, Time: 15:45GMT, Alt.: 2100ft.

1 Raw CASI data showing errors due to roll and pitch.

2 Roll corrected CASI data showing visually correct imagery but with the wrong geometric orientation.

3 Geo-corrected CASI data showing corrections for heading and geometrically square pixels.

True colour composite CASI data consists of bands 7 (680nm-685nm), 4 (593nm-603nm) and 2 (480nm-500nm).

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1

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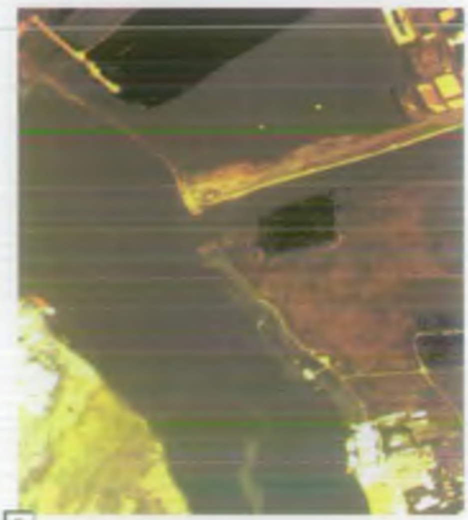

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Image Location: River Tees, Teesport, Middlesbrough.
Image Date: 21st November 1992, 12:12pm & 12:21pm

No roll correction available for CASI imagery

Scale [1] & [2] (approx) 0 — 1km

1 Enhanced true colour composite image compiled from CASI data, showing surface pollution from industrial outfalls

2 Thermal mosaic sensed at the same time as [1] showing several warm water outfalls (dark) and the tidal front

3 Synthesis of 12:12 and 12:21 thermal images. The tidal front has moved, dissipating and extending industrial outfall plumes

4 Custom enhanced section of [1]. Surface pollution is clearly seen coming from outfall 2.

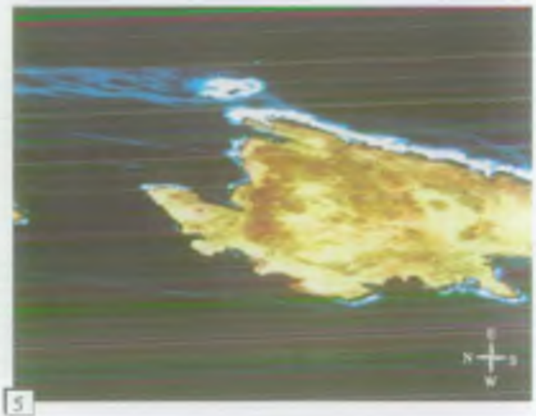
5 Custom enhanced section of [1]. Outfall 1 (clear in [2]) cannot be seen, indicating warm water with no visible pollutants.

1

2

3

4



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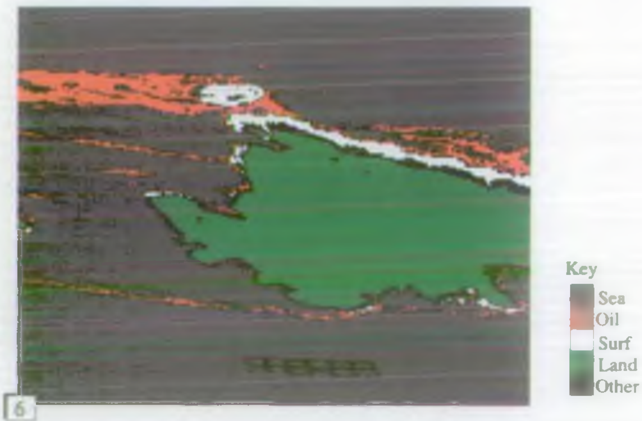

6

Image Location: [1] & [2]: Garth Ness, Shetland. [5] & [6] S. Havra, Shetland.
Image Date: [1] & [2]: 13th Jan 1993, [5] & [6]: 14th Jan 1993

1 True colour image derived from the CASI imager standard bandset 7,4 &2, from 9000 ft giving an overview of the wreck site

2 Image derived from [1] using principal component transform. Components 1,4 &5 clearly reveal the extent of the oil spill.

3 & 4 Extracts of maps showing the location of images [1] & [2] in [3], and the general area of images [5] & [6] in [4]

5 False colour image of section of South Havra showing streaks of oil threatening a floating fish farm (centre bottom)

6 Classification of image [5] splitting it into surfaces (see key). This technique could be rapidly extrapolated over large areas.

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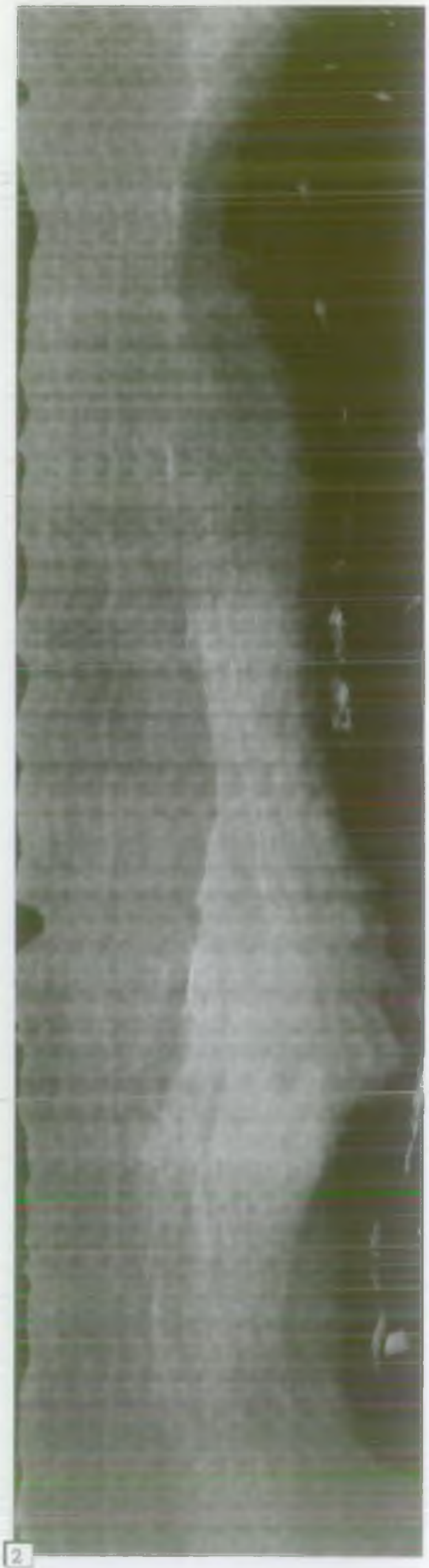
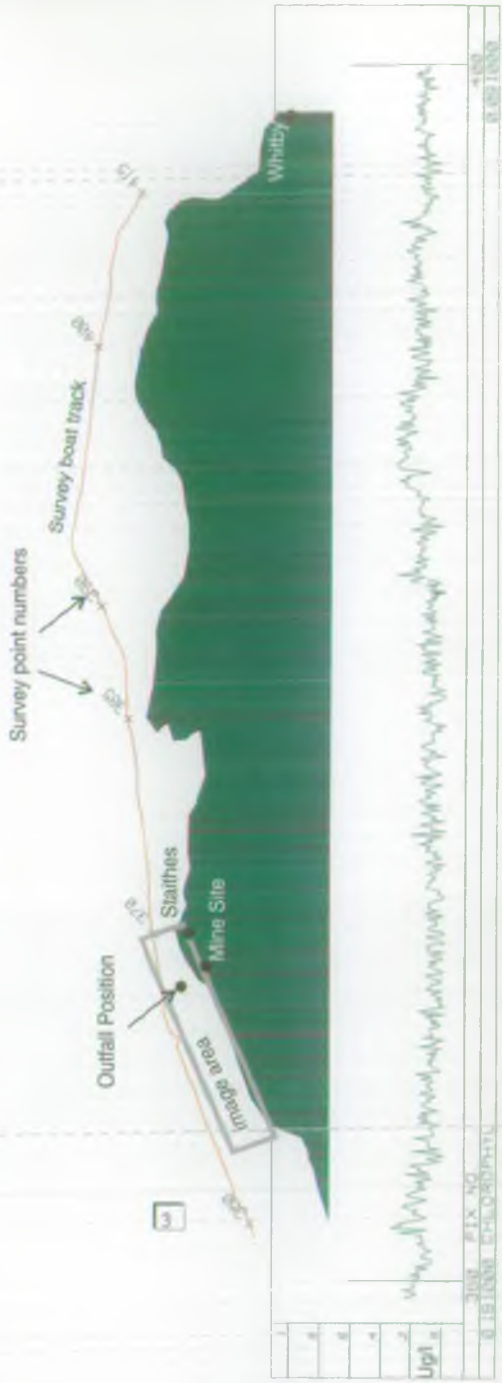
1



2



3

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Image Location: Staithes area, North Yorkshire
Image Date: 24th May 1993

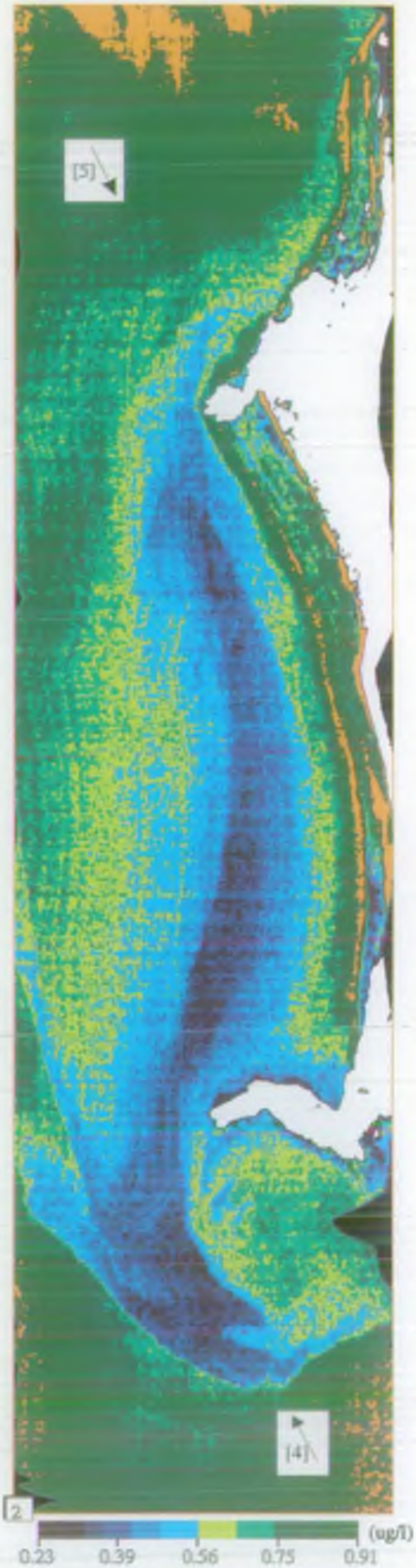
0 Scale (approx) 2 km

1 CASI true colour image showing approx 5.5Km trail of effluent from a potash mine outfall at Boulby.

2 Chlorophyll concentration image (fluorescence line height). The chlorophyll concentration inshore of the outfall trail is increased

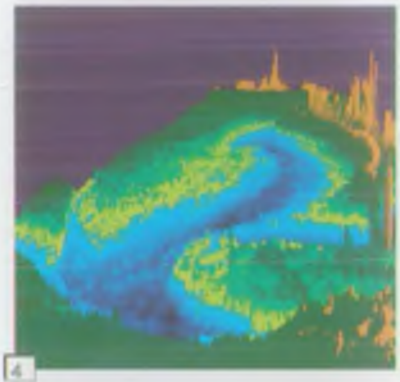
3 Synthesis of survey boat data for the area (survey date 6th May). Low chlorophyll values were found along the boat track, which was offshore from the outfall. This pattern of discharge from the outfall has been observed in other seasonal surveys.

1



2

3



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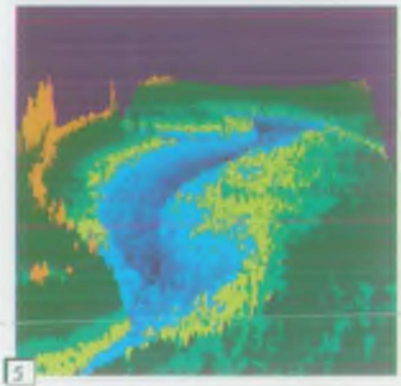
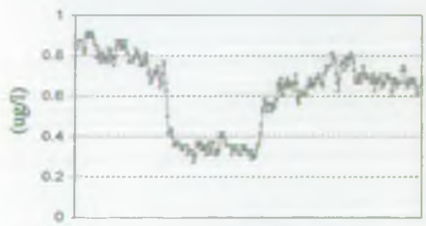


5



6

Image Location: Worms Head, Gower Peninsula, Wales
Image Date: February 23rd 1993

0 Scale (approx) 3km

N S W E

1 Enhanced true colour composite image compiled from CASI scanner channels 7,4 & 2

2 Chlorophyll concentration image derived using fluorescence line height and coloured as per scale

3 Enhanced section of image [1] as indicated, showing boundary between coastal and riverine waters

4 & 5 Perspective views of image [2] using chlorophyll concentration as height information. View positions as shown on [2]

6 Chlorophyll concentration plotted along the line shown in [1], showing sharp contrasts between coastal and riverine waters

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The River Humber, 30 June 1995.

A true colour composite mosaic of five CASI images showing an area of the Humber approximately 28km x 20km. The misty lines are due to atmospheric edge effects caused by a difference in pathlength between the centre and edges of an image.

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3.3	**SENSOR NAME:**	**Airborne Thematic Mapper (ATM)** (Daedalus AADS1268)
	Sensor Type:	Passive
	Wavebands:	1. 0.42 - 0.45 µm (blue) 2. 0.45 - 0.52 µm (blue) 3. 0.52 - 0.60 µm (green) 4. 0.605-0.625 µm (green) 5. 0.63 - 0.69 µm (red) 6. 0.695-0.75 µm (near infra-red) 7. 0.76 - 0.90 µm (near infra-red) 8. 0.91 - 1.05 µm (near infra-red) 9. 1.55 - 1.75 µm (middle infra-red) 10.2.08 - 2.35 µm (middle infra-red) 11.8.5 - 13.0 µm (thermal infra-red)
	Image Extent:	1.4 kilometres across track at 1000 metres altitude.
	Spatial Resolution:	1.3 metres at 1000 metres altitude.
	Appropriate Scales:	1:10,000

Typical Applications

Water Quality:	Suspended sediment studies. Chlorophyll concentration studies. Pollution monitoring.
Water Resources:	Water body mapping. Geological mapping.
Flood Defence:	Coastal inventories.
Fisheries:	Marine, estuarine and lake thermal mapping.
Recreation and Conservation:	Vegetation mapping, Habitat classification.

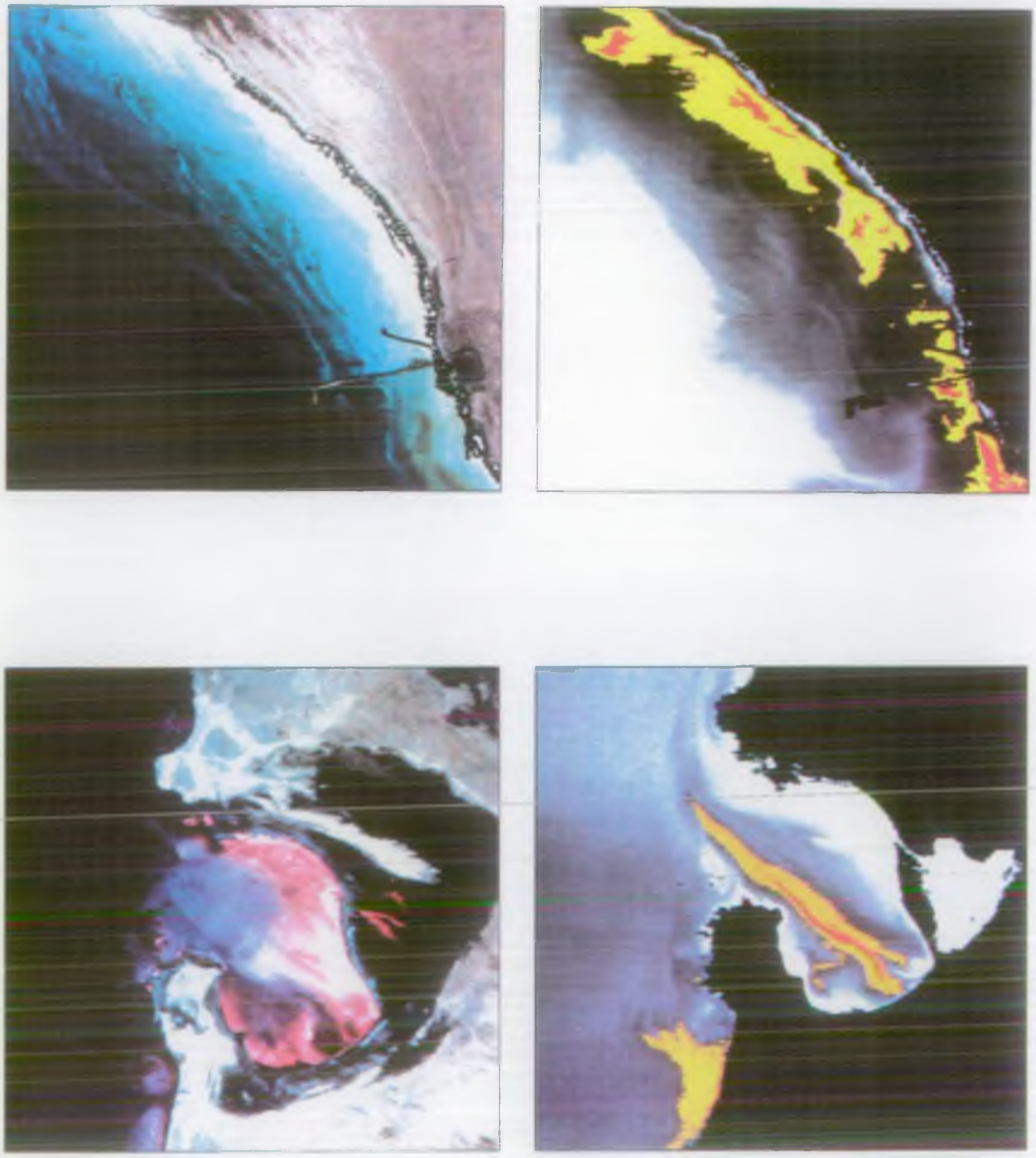


Figure 3.1 Airborne Thematic Mapper Imagery and Thermal Signature. The images comprise two pairs: the images to the left are false colour composites of the ATM data, the images to the right use only the thermal band with low temperature anomalies highlighted in red and yellow.

3.4 SENSOR NAME: Digital Multi-Spectral Video (DMSV)

Sensor Type: Passive

Wavebands: Four programmable bands in the visible and NIR region.

Image Extent: At 500 m altitude, 250 m x 250 m
At 3000 m altitude, 1500 m x 1200 m

Spatial Resolution: At 500 m altitude, 0.3 metres
At 3000m altitude, 2 metres

Appropriate Scales: 1:5,000/1:10,000

Typical Applications

Water Quality: Suspended sediment studies.
Chlorophyll concentration mapping.
Algal bloom monitoring.
Pollution monitoring.

Water Resources: Water body mapping.

Flood Defence: Coastal inventories.

Recreation and Conservation: Vegetation mapping/Species mapping.
Habitat classification.

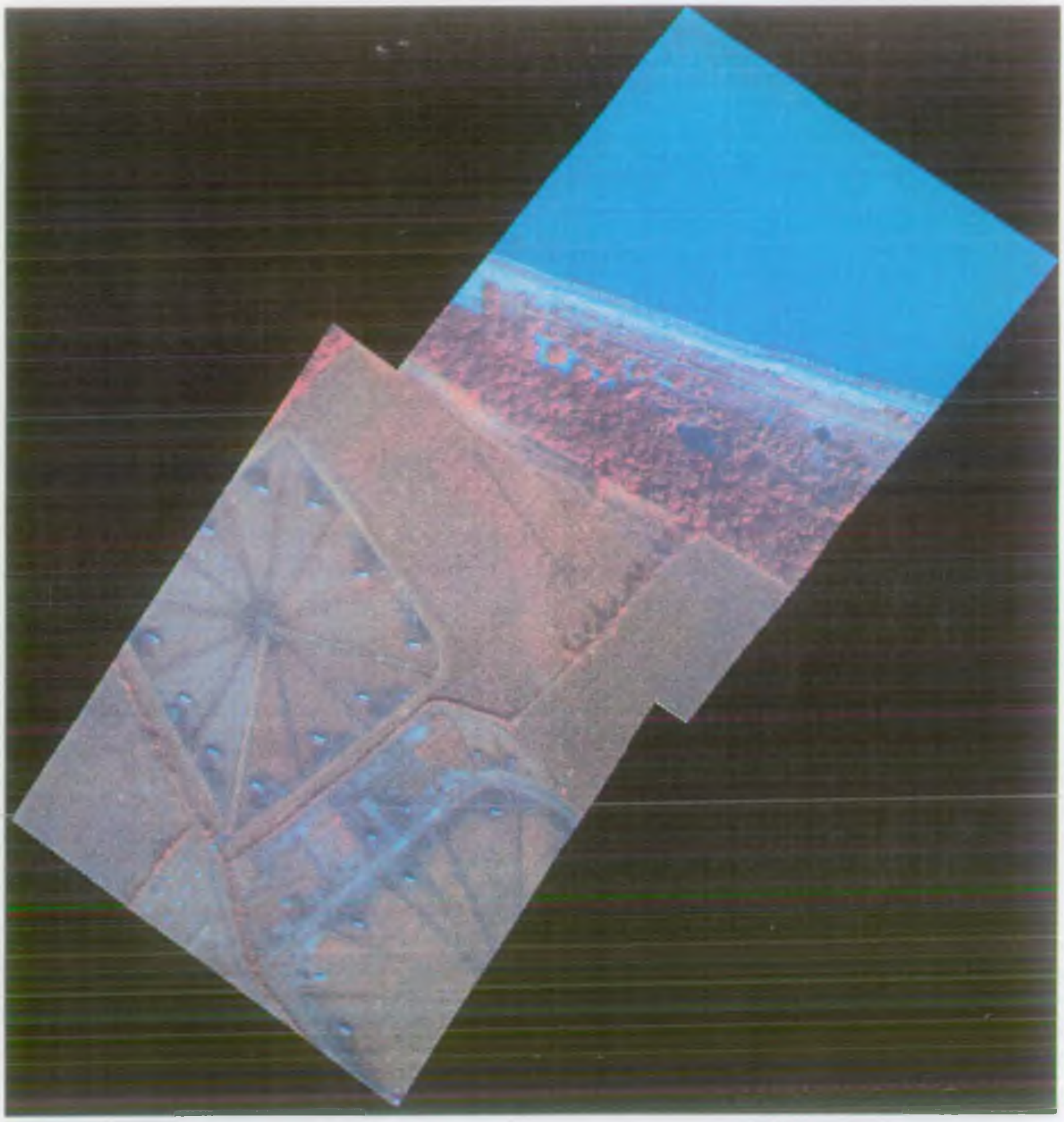


Figure 3.2 A Digital Multispectral Video Image

3.5 SENSOR NAME: TALYTHERM INFRA-RED IMAGING SYSTEM

Wavebands:
Standard: 8.0 -- 13.0 µm (thermal infra-red)
Special: 3.0 - 5.0 µm (thermal infra-red)

Thermal Resolution 0.03°C minimum detectable dynamic temperature difference.

Scan Rate: 50 fields per second, similar full TV rate.

Spatial Resolution: 512 samples per line
512 lines per frame

Appropriate Scales: Depends on requirements - 1:5,000

Typical Applications

Water Quality:	Pollution monitoring - marine & freshwater Study of outfall mixing zones. Oil spill detection.
Flood Defence:	Detecting defence weak spots and leaks
Recreation and Conservation:	Monitoring wetlands
Fisheries	Study of freshwater mixing zones

3.6 SENSOR NAME: Synthetic Aperture Radar (SAR)

Wavebands: Usually C-Band 5.3GHz
or L-Band 1.3GHz

Image Extent: Swath Width approx. 3000 metres.

Spatial Resolution: Up to 2.5 metres

Appropriate Scales: 1:10,000

Typical Applications

Water Quality:	Mapping pollution incidents
Water Resources:	Change detection
Flood Defence:	Wave regime/bottom topography studies
Navigation:	Ship traffic analysis

3.7 AERIAL PHOTOGRAPHY SYNOPSIS

Wavebands: Visible colour, panchromatic black-and-white, infra-red false colour
Print format: 9" by 9" colour / black-and-white

Data Availability: Dates: 1991 - 1995 ongoing.
Coverage: Full UK coverage
Air photo's held by county can be used for temporal changes

Spatial Resolution: Varies with scale, e.g. resolution at 1:3,000 scale is approx. 0.15 m resolution at 1:25,000 scale is approx. 2.5 m.

Coverage: Varies with scale, for example

1:3,000	0.68 x 0.68 km
1:10,000	2.29 x 2.29 km
1:25,000	5.71 x 5.71 km

Typical Applications:

- General Planning
- Land Use and land capability
- Soils, Geology
- Forestry
- Development
- Water
- Boundary Disputes
- Public enquiries
- Pollution
- Mining and Quarrying
- Agriculture
- Transport and Civil Engineering

Practical Uses:

The traditional use of vertical aerial photography is well documented. The more recent developments are perhaps more of interest to users working with geographic information capture, storage and manipulation. New methodologies are being developed whereby on screen digitising of data to either a map, digital photo or orthophoto backdrop can be used.

3.7.1 Digital Photos

Digital photos are produced from scanned colour vertical aerial photography. The characteristics of the end product are governed by the scale of the photography and the dots per inch (dpi) selected at the time of scanning. This in turn will be governed by the available budget and the use to which the scanned data is to be put. The normal range will be 300 - 600 dpi.

Figure 3.3 A 1:25,000 Contact Scale Aerial Photograph of Southern Loch Lomond.

The result is a geo-referenced seam-free mosaic which can be displayed on screen, "roamed" around and zoomed into. A separate licence would be required for clients to produce hardcopy using their own hardware / software. A near-photographic quality print can be supplied according to the user's requirements.

3.7.2 Orthophotos

Orthophotos are also produced from colour vertical aerial photography or satellite imagery. The scanned data is processed to remove distortion due to the relief of the ground and the camera system itself, producing an image which is essentially a vertical view of the ground at every point in the image. This process uses the overlap area between successive flight lines of photographs. In this region one can obtain a stereo view of the ground, allowing the extraction of height information and the construction of a Digital Elevation Model. Using this model, the image of the overlap region can then be corrected, in a manner analogous to a photogrammetric plotter, to account for relief effects.

Where no mapping exists, this product can provide a useful alternative. If a satellite image is used, a geographical grid / projection can be provided to complete the comparison to mapping.

3.7.3 DEM Production

A Digital Elevation Model (DEM) and Digital Terrain Model (DTM) are similar products; both are essentially raster datasets, in which the value of each pixel reflects the elevation of the ground at that point. Both are created in a similar way. In a DEM, the elevation includes structures and features standing above ground level, such as buildings, forest stands and so on. A DTM reflects the true ground level.

Using either aerial photography or satellite stereo images, a grid of levels is created by observation. This can be done manually by a human operator, or automatically generated using auto-correlation techniques. Alternatively, the ground elevation can be measured using laser altimeter or similar instrument. Sophisticated processing creates a three dimensional image which can be exported in raster format to the appropriate client software applications. The spatial and height resolution will depend on the original data and the dpi used in scanning.

Orthophoto **Killegar, Dublin** **1:10 000**

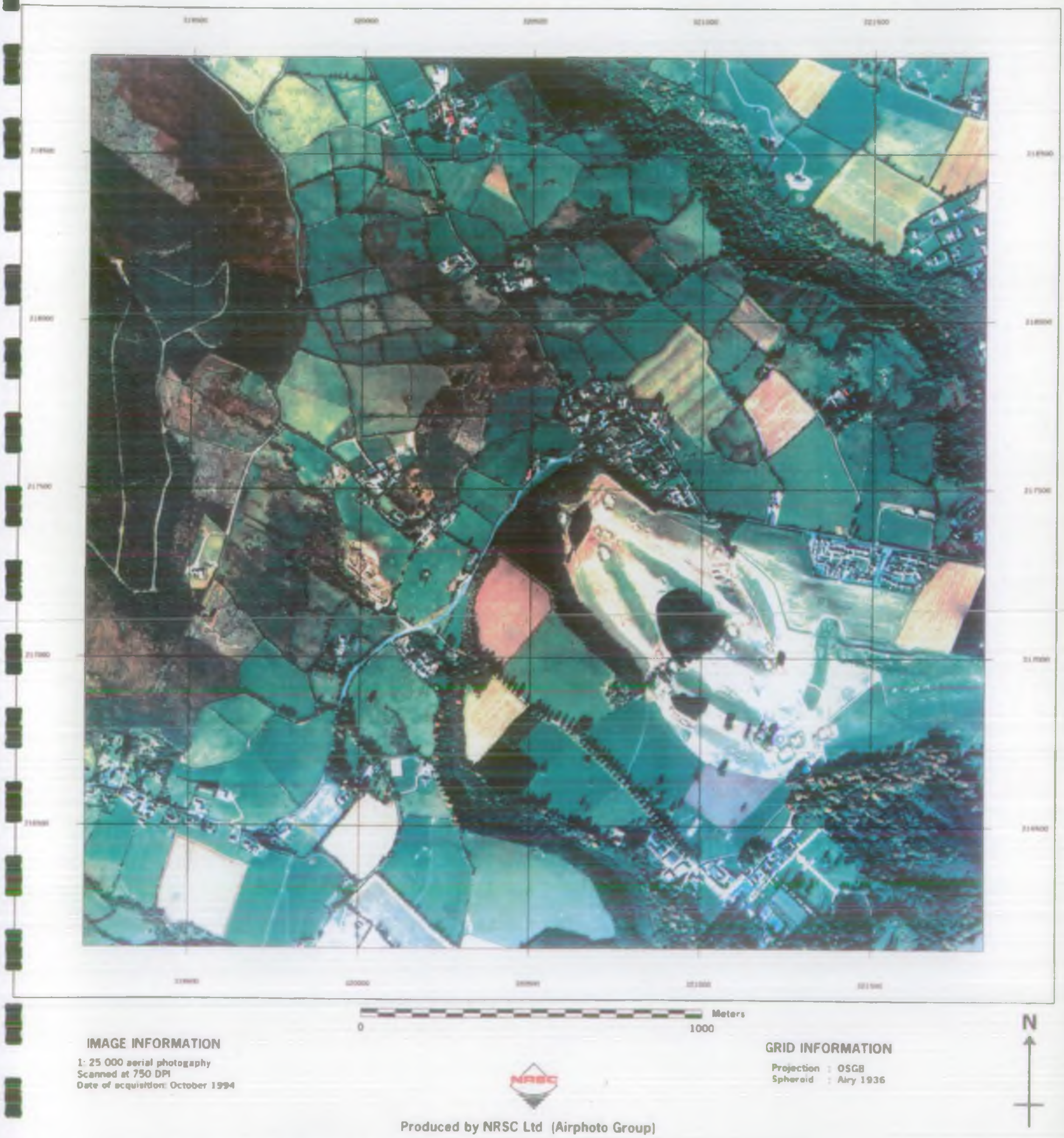


Figure 3.4 An Orthophoto - Orthorectified Aerial Photograph

3.8 LASER SENSORS

3.8.1 LIDAR System Description.

LIDAR is an acronym for Light Detection and Ranging, and is a general term for a number of sensing systems based on the use of lasers. LIDAR is basically an active system, which operates in a manner analogous to a conventional radar or radar altimeter, except that a laser is used to provide the illumination rather than microwaves. The laser sends out a pulse of light, and the reflection of the light from the surface (the "echo") is detected. The time difference between the emission of the initial pulse and the receipt of any echoes can then be interpreted to give the distance from the sensor to the surface. LIDARs are currently deployed only on airborne platforms.

3.8.2 Applications

- **Bathymetry:** LIDAR sensors offer an accurate way of determining local scale bathymetry, in coastal or estuarine regions. When used over a water body, the LIDAR will detect a strong reflection from the surface of the water, followed after a short delay by a fainter reflection from the bottom. The delay time indicates the water depth. This method is dependant on the clarity of the water.

- **Topographic Mapping:** The altimeter capability of LIDAR can be used to map elevation and topography. This useful in, for example, the creation of flood plain maps.

- **Forestry studies:** LIDAR can be employed to map heights of forest stands, and estimate forestry biomass. The stand height can be computed in a manner similar to the bathymetry application, comparing the delay times of the reflections from the tops of the trees with reflections from the ground.

- **Biomass estimation, oil slick and water quality assessment:** These are applications of laser induced fluorescence, and are discussed further in the following section.

3.8.3 Fluorescence Line Height (FLH) and Laser Induced Fluorescence (LIF)

These techniques utilise the phenomenon of fluorescence exhibited in certain materials. Light at a particular wavelength is absorbed by the material. A proportion of the energy is then re-emitted by the material a short time later, usually at a slightly longer wavelength. The source of the fluorescence stimulus can be either natural light (sunlight) or light from a laser. The wavelength at which absorption and fluorescence occur is characteristic of a given material, and it is these properties which can be exploited as a remote sensing technique.

FLH: Mapping phytoplankton distribution
This technique exploits the characteristic sunlight stimulated fluorescence line of chlorophyll at a wavelength of 0.685 μm, primarily to map phytoplankton distribution in water bodies. Measurement of this quantity has been performed using a *Fluorescence Line Imager* (FLI), an airborne imaging spectrometer type instrument, with an extremely high signal-to-noise ratio (about 2000:1) which is necessary to distinguish the fluorescence signal from background radiance at the same wavelength. The FLI was the prototype of the CASI scanner; indeed, CASI can be used for FLH applications.

The FLI records an image of the water body, and a detailed spectral signature from a number of areas across the surface is derived. Fluorescence from the chlorophyll appears as a peak at the fluorescence wavelength, and the relative height of this peak compared to the radiances at longer and shorter wavelengths can be calibrated in terms of chlorophyll concentration in mg m^{-3}. Since this method deals in relative quantities, it is (relatively) insensitive to atmospheric effects, although some atmospheric correction is still required.

The same principle can also be applied to biomass estimation applications. For instance, measuring the fluorescence from green forest canopies.

LIF: Applications of laser fluorosensors
Laser fluorosensors use a laser beam operating at ultra violet wavelengths (around 0.3 μm) to stimulate fluorescence in materials, and record the resulting radiance. The main driving force behind the development of these instruments has been in relation to the oil industry, but there are numerous other applications.

Using a fluorosensor, it is possible to not only identify oil films on the surface, but to measure the thickness of the film and even determine broadly the types of oil present, enabling accurate mapping of the extent and nature of a spill. This idea can also be extended to following the progress of dye tracers released into a water body to measure current flow and other such parametres. LIF is also observed in chlorophyll, giving laser fluorosensors an application in water quality applications as well as FLI's. Other material suspended in water, such as non-biological sediments and yellow substances are also amenable to measurement by this method.

Section No.4

Future Sensors

In the near future two new satellites are to be launched, one with passive sensors and the other active. The SeaWiFS passive sensor is to be launched on board the SEASTAR satellite. Launch has been delayed but it is currently due for May/September 1995. This is a sensor dedicated to ocean colour studies similar to, but improving upon, the Coastal Zone Colour Scanner (CZCS) of the 1980s. The Canadian RADARSAT satellite will carry another SAR instrument which will mean, when combined with ERS-1, a total coverage of UK waters every three days.

Other significant satellites and sensors which are planned for the late 1990's are the European ENVISAT mission, the next SPOT spacecraft, and commercial U.S. imaging systems, Eyeglass and WorldView. Precise details on data cost and availability, and exact details of theses future systems have not yet been established.

ENVISAT will be another polar orbiting platform, carrying a comprehensive package of remote sensing instruments for a variety of environmental studies, including ocean / ice, atmospheric chemistry, ozone and climate change studies, Earth resources and process monitoring. The most interesting instrument from an NRA perspective will probably be MERIS, an imaging spectrometer type instrument designed primarily for ocean colour investigations.

SPOT-4 and SPOT-5 will be improved versions of the existing SPOT system. SPOT-4 will be based on the existing spacecraft, with an additional spectral band in the mid infra-red and improved vegetation monitoring capabilities. It is due for launch in 1997. SPOT-5 will be a radically new system, with improved optical sensors and ground resolution of 5 - 10 m. A tentative launch date is 1999 - 2000.

Eyeglass and WorldView will both be commercially built and operated satellites, returning panchromatic data with a spatial resolution of 1 - 3 metres, which will be available to government and private sector users. These are scheduled for launch in 1997 or 1998.

4.1 SATELLITE NAME: SEASTAR

4.1.1 Sensor Name: Sea Viewing Wide Field-of-view Sensor (SeaWiFS)

Data Availability: **Dates:** To be launched in 1995
Coverage: Continuos over U.K.

Wavebands:
1. 0.402-0.422 μm (visible)
2. 0.433-0.453 μm (visible)
3. 0.480-0.500 μm (visible)
4. 0.500-0.520 μm (visible)
5. 0.545-0.565 μm (visible)
6. 0.660-0.680 μm (visible)
7. 0.745-0.785 μm (near infra-red)
8. 0.845-0.885 μm (near infra-red)

Image Extent: Unknown at present.

Spatial Resolution: **Low Resolution:** 4.5 kilometres
High Resolution: 1.13 kilometres

Appropriate Scales: 1:1,000,000

Repeat Frequency: 1 day

Typical Applications

Water Quality: Chlorophyll / suspended sediment monitoring
Circulation
Mixing zones

Approximate Cost: Unknown at present.

4.2 SATELLITE NAME: RADARSAT

4.2.1 Sensor Name: RADARSAT Synthetic Aperture Radar (SAR)

Data Availability: **Dates:** 1995 onwards
Coverage: Continuous over U.K.

Frequency: 5.3 GHz (C-band)

Image Extent: 100 km x 100 km

Spatial Resolution: 12.5 metres

Appropriate Scales: 1:50,000/1:25,000

Repeat Frequency: 3 days (16 days)

Typical Applications

Water Quality: Oil pollution monitoring.
Slick mapping.

Flood Defence: Bathymetric mapping.

Recreation and Conservation: Flooding analysis.

Approximate Cost: Unknown at present.

4.3 SATELLITE NAME: ENVISAT

4.3.1 Sensor Name: Medium Resolution Imaging Spectrometer (MERIS)

Data Availability: Launch planned for 1998
Can cover UK every 3 days.

Wavebands: Up to 15 spectral bands, with programmable positions and widths, between 0.400 μm and 1.050 μm (visible blue to near infra-red), with a spectral resolution of 0.0025 μm.

Image Extent: 1,450 km swath width

Spatial Resolution: 300 m (high resolution), 1,200 m (low resolution)

Appropriate scales: 1:500,000 - 1:1,000,000

Repeat Frequency: 3 days.

Typical Applications: Coastal water quality mapping, suspended sediment transport, algae mapping.

Approximate Cost: Unknown at present.

4.4 SATELLITE NAME: EOS / AM-1

4.4.1 Sensor Name: Moderate Resolution Imaging Spectrometer (MODIS)

Data Availability: Launch planned for 1998 - 2000

Wavebands: 36 wavebands spanning various parts of the visible, near-, mid- and thermal infra-red (between 0.415 µm and 14.24 µm). Spectral resolution will vary between 0.01 µm in the visible ocean colour bands, to 0.5 µm in the thermal bands.

Image Extent: 2,330 km swath width

Spatial Resolution: 1 km in most bands; some bands have 250 m or 500 m.

Appropriate scales: 1:500,000 - 1:1,000,000

Repeat Frequency: 2 days

Typical Applications: Coastal water quality mapping, suspended sediment transport, algae mapping, sea surface temperature mapping. Also land cover discrimination, snow and ice cover, surface temperature, fire detection and mapping.

Approximate Cost: Unknown at present.

Section No.5

Digital Image Processing

5.1 INTRODUCTION

Image processing is an integral part of remote sensing, and the natural affinity between modern digital scanners and digital image processing techniques enables many seemingly complicated and sophisticated remote sensing procedures to be applied to a dataset relatively easily. Image processing is also a vital step in the production of *value-added products*, for instance the conversion of a thermal image into a sea surface temperature map.

This section gives an introduction to some of the most common and important image processing techniques which are used in remote sensing, along with some relevant applications.

5.2 DIGITAL DATA

5.2.1 Some Basic Concepts

The development of digital scanners coupled with advances in computing power mean that remote sensing data is now handled almost exclusively in the digital domain; i.e. a remote sensing image is not stored as a photographic print, but rather as a file of numbers held on a computer disk. While this perhaps involves another layer of complexity to the interpretation of an image, it in fact offers a tremendous increase in flexibility and speed of data handling. Because the digital approach comes naturally to contemporary remote sensing, the science of digital image processing is intimately linked with the application of remote sensing techniques. Digital image processing allows manipulation of the data, such as changing the contrast of an image, or transforming it into a specific map projection, to be performed automatically in minutes.

The Byte

The common unit of digital information storage is the byte. This is basically the memory space needed to store a character of text. Since this is not very large, the capacity of a particular medium is expressed in the following multiples:

Unit	Description	Abbreviation
Kilobyte	1,024 bytes	K (or Kb)
Megabyte	1,024 Kb or 1,048,576 bytes	Mb
Gigabyte	1,024 Mb or 1.07 billion bytes	Gb

By way of comparison, an A4 page of text generated by a word processor takes up about 2 Kb of disk space. A full LANDSAT Thematic Mapper image, covering an area about 185 km square with all seven bands takes up about 280 Mb. A typical CASI image is 50 - 100 Mb.

Rasters and Pixels

A digital image is basically a grid of numbers, where each number represents the brightness of that particular point in the image. The grid is referred to as a *raster*, each position in the grid which holds a number is called a *pixel* (short for "picture element"). One pixel is generally represented by one byte on the storage medium, depending of the radiometric resolution of the sensor that acquired the image. Some sensors with very high radiometric resolution (see previous), such as some airborne scanners, represent each pixel by two or more bytes. This influences the total size of the dataset.

Digital Numbers (DN)

The phrase digital number refers to the value contained in each pixel in the raster. This generally reflects the brightness of the image at that point, but can also be used to encode other kinds of information. The values that can be stored in one byte range from 0 to 255, a total of 256 values. If two bytes are used, the range of values increase to 0 to 65,535.

Dynamic Range, Quantization and Pixel Depth

This section is included for completeness, as the terms defined here are commonly used in describing datasets, but a full description of the subject matter is outside the scope of this discussion.

The range of values which can be represented by a given number of bytes is known as the *dynamic range* or *pixel depth*. However, the convention is to describe this quantity in terms of the number of *bits* in each pixel, rather than the number of bytes. There are eight bits in one byte, so data with a dynamic range of 0 to 255 is referred to as *8-bit data*. Data stored in two bytes, with a dynamic range of 0 to 65,535 is therefore *16-bit data*.

This concept is also applied to the radiometric resolution of a sensor, i.e. the smallest difference in radiance that the sensor can detect. In this context, it is known as *quantization.* Most remote sensing data is conventionally 8-bit or 16-bit (radar data is usually 16-bit). However, the reader should be aware that some specialised sensors, particularly airborne scanners, return 10 or 12-bit data.

5.2.2 Data Storage Media.

As computer processing power has increased, so too has the sophistication and capacity of devices to store data in an electronic format, with the result that there are numerous types of storage media, mostly based on magnetic tape. The following is a brief list of common storage devices, and their characteristics.

Floppy Disk.
This is probably the most familiar type of storage mediium, being used with general office computers such as PC's and Macintoshes. The small 3.5 inch disk is now becoming standard, taking over from the older 5.25 inch disk. Their capacity is relatively small (a maximum of only 2 Mb), so their use with remote sensing data is very limited.

Computer Compatible Tape (CCT)
This comes on 12 inch reels, and is available in a number of "densities" i.e. the maximum amount of information that can be stored on one tape. These are more appropriate to remote sensing data, as one reel can store up to about 150 Mb. CCT's are generally described in terms of "bytes per inch".

High Density Data Tape (HDDT)
HDDT is slowly superseding CCT, as it is more compact and has much higher capacity. HDDT comes in small cartridges, similar to the mini video cassettes used in camcorders. A cartridge of this type has a capacity of about 5 Gb (5,000 Mb), and may also be referred to as an "Exabyte" after a particular make of HDDT.

Optical Disk (CD-ROM, WORM)
Optical disks are similar to conventional audio compact disks, and have a data capacity of up to10 Gb. The NRA uses 1 gigabyte rewritable optical disks which have advantages for archive uses, due to their compactness, high capacity, and robustness. In the near future the whole coastal survey will be compressed onto one CD for distribution. WORM (Write Once, Read Many) drives allow users to write data onto blank disks.

HDDT and CD-ROM are currently the favoured form of storage media, for their very large capacities and compactness for archiving and transport. CCT is, however, still widely used as a standard medium for transporting data.

5.2.3 Data Formats

The actual image data of a remote sensing image may only be one component (albeit the most important) of the full information which the remote sensing specialist needs to carry out an interpretation. Frequently, ancillary information such as the geographical location of the image, the date it was acquired, and the wavebands used are also packaged along with the image data, either in the same file, or in an additional file on the same tape (known as a *header file*).

Due to the international nature of the satellite industry, there is no one standard for packaging all this information together. Individual ground stations and data supply organisations in different parts of the world may have their own data format. Commercial image processing software packages also have their own formats, although most will support conversion of data from one format to another.

However, a customer ordering satellite data through a supplier will generally not have to worry about this, since the supplier can arrange for the data to be converted to a format of the customer's specification, including hardcopy output or photographic print.

5.3. DIGITAL IMAGE PROCESSING FUNCTIONALITY

5.3.1 Basic Processing of Data

The raw data as transmitted from the satellite sensor to the ground station is virtually unusable for any application, due to the large number of distortions caused by the relative motion of the satellite over the Earth, the curvature of the Earth and so forth. Additionally, the data may need to be calibrated for effects in the sensor. All these distortions will be known to a high degree of accuracy, enabling the ground station to correct for them, and process the raw data into a usable image. This initial stage is known as *system correction* and *radiometric correction.*

5.3.2 Further Processing

Once system and radiometric correction has been performed, the image is in the state in which it can be supplied to a user. However, further processing is required to employ the image in a particular application. The image may need to be converted into a specific map projection or assigned geographic coordinates. It may be very low contrast and difficult to inspect, and be affected by *noise* (that is, random fluctuations in the recorded radiance from a variety of sources, which give the image a grainy appearance).

The removal or alleviation of unwanted effects, and the subsequent conversion of the image into a value-added product is the province of *image processing* as a science. This is accomplished in an image processing system, generally a suite of software for manipulating images. Numerous commercial packages are available for performing these functions. These can operate at a high level, requiring little programming experience, where the user can run a number of pre-written programs to do certain jobs. Systems such as ERDAS Imagine, PCI and ER-Mapper are examples of this. Other systems, such as IDL and HIPS enable users to write their own programs to perform specific or specialised operations. These offer greater flexibility, traded off against increased complexity, and may require more general programming expertise.

Although precise capabilities vary from system to system, almost all suites will offer the same basic functionality, the need for which is described in the following sections.

5.4. IMAGE DISPLAY

5.4.1 Greyscale Representation

The display of digital data as an image is, obviously, a fundamental function of image processing. However, digital data can be used to do more than simply see what the image looks like.

As previously discussed above, a remote sensing image is formed by an array of pixels, each pixel usually containing a number from 0 to 255 which represents the brightness of the image at that point. To display an image on a computer screen, each pixel is displayed as a shade of grey, conventionally displaying pixels with a DN of 0 as black, a DN of 1 to 254 as a grey shade, and a DN of 255 as white. This is referred to as a *greyscale* representation.

Effectively, this means that an image can be displayed with 256 shades of grey; this is more than the human eye can distinguish, and so is sufficient to show up most detail. In addition, the image appears identical to a black-and-white photograph, making it familiar to the human observer, and easy to interpret.

5.4.2 Pseudocolour Representation

The human eye can discriminate many more shades of colour than it can shades of grey. While a black-and-white representation is easy to inspect, fine detail in the image may not be easily visible. An alternative therefore is to assign a range of colours to the DN's of each pixel rather than a shade of grey. For instance, DN zero may be represented by red, going through the spectrum of shade of orange, yellow, green, etc., for intermediate DN's, up to blue for a DN of 255. In this way, fine features in the image, represented by small variations of DN may be more clearly visible. The drawback of this technique is that the colours the operator assigns to the DN range are entirely arbitrary (hence the name *pseudocolour*), and have no direct relationship to the features of the image. This can make the image difficult to interpret. Examples of the same image displayed in both greyscale and pseudocolour representation, are shown in Figure 5.1.

5.4.3 Colour Composites

The above techniques display a monochrome representation of the image. The effect is the same as in a black and white photograph, and no colour, or spectral, information is conveyed. The technique of colour compositing allows images of the scene in three wavebands to be superimposed on the computer monitor, one band in red, one in green and one in blue. Different amounts of these three primary colours then add together to make any other colour (This is exactly the same as the process by which a colour television produces its image). This produces an *RGB composite* (short for Red, Green, Blue).

A sensor such as the LANDSAT Thematic Mapper acquires images in the visible red, visible green and visible blue wavebands. Where these are displayed in the corresponding colours on the screen, the result is an approximation of what the scene would look like to the human eye. This is called a *true colour composite*. However, *any* waveband can be displayed in the colour channels, especially those bands which lie outside the range perceptible to the eye. This produces a visual image of the spectral information contained in the bands of the dataset, which is known as a *false colour composite*. One common application of this is to display the near infra-red band in red, the visible red band in green and the visible green in blue (for instance with Thematic Mapper, to have Band 4 in red, Band 3 in green and Band 2 in blue). This combination causes vegetation to show up as bright red, and is commonly used in vegetation mapping and determination of vegetation health.

For many applications, this information, the way in which radiance from the same target changes from one waveband to the next, is of great importance, and leads to the field of *multispectral analysis* of the data. This is further discussed in Section 5.8.6.

5.5 CONTRAST ENHANCEMENT

5.5.1 Histograms and Contrast Stretching

In general, the raw data of an image will only use a small part of the available dynamic range of the sensor. If the unmodified image is displayed on a screen, it will appear with very low contrast, i.e. generally dark or bright, and little detail will be visible. This situation is overcome by a process of contrast enhancement; Figure 5.2 shows and image before and after this kind of enhancement.

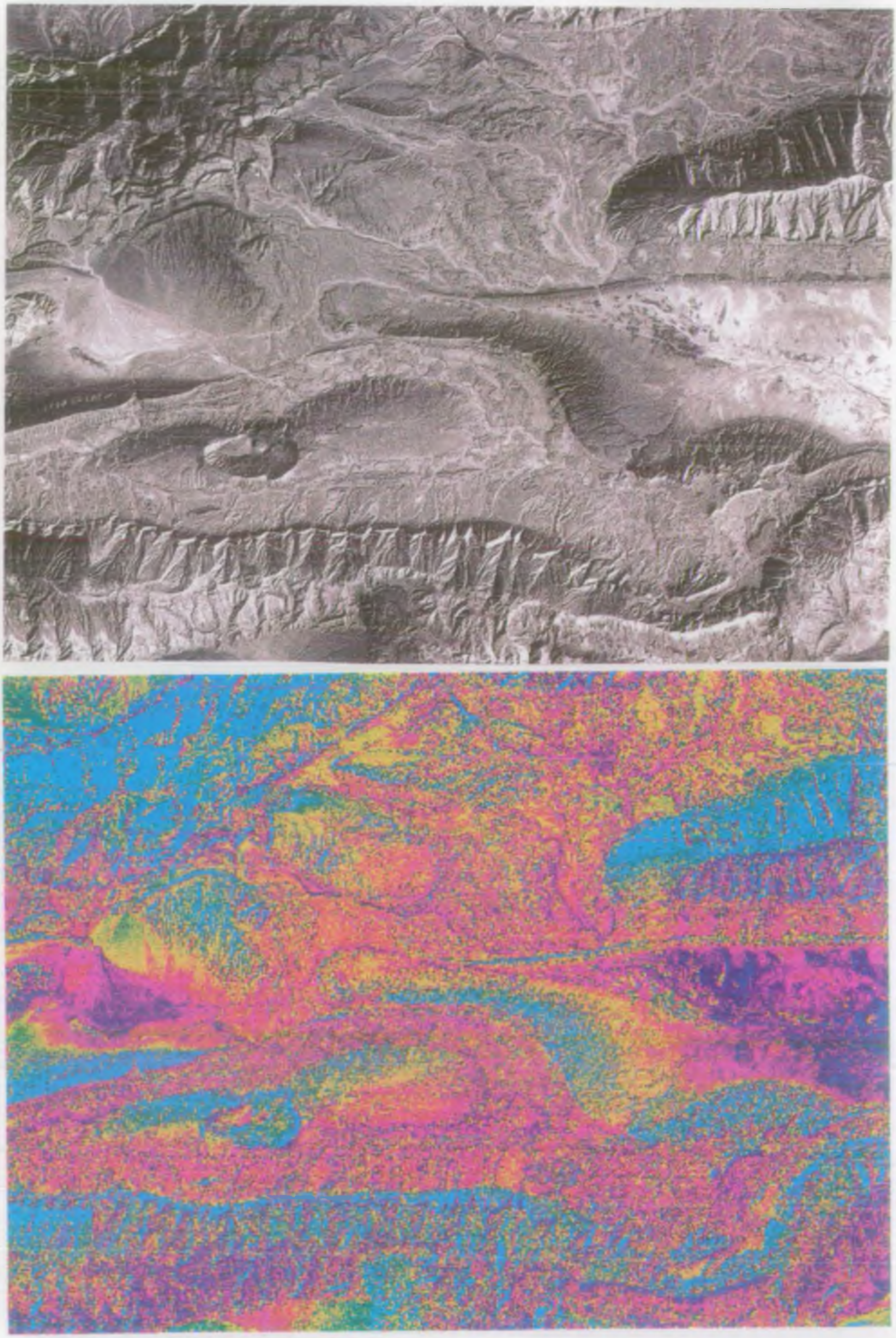


Figure 5.1 Greyscale and Pseudocolour Images

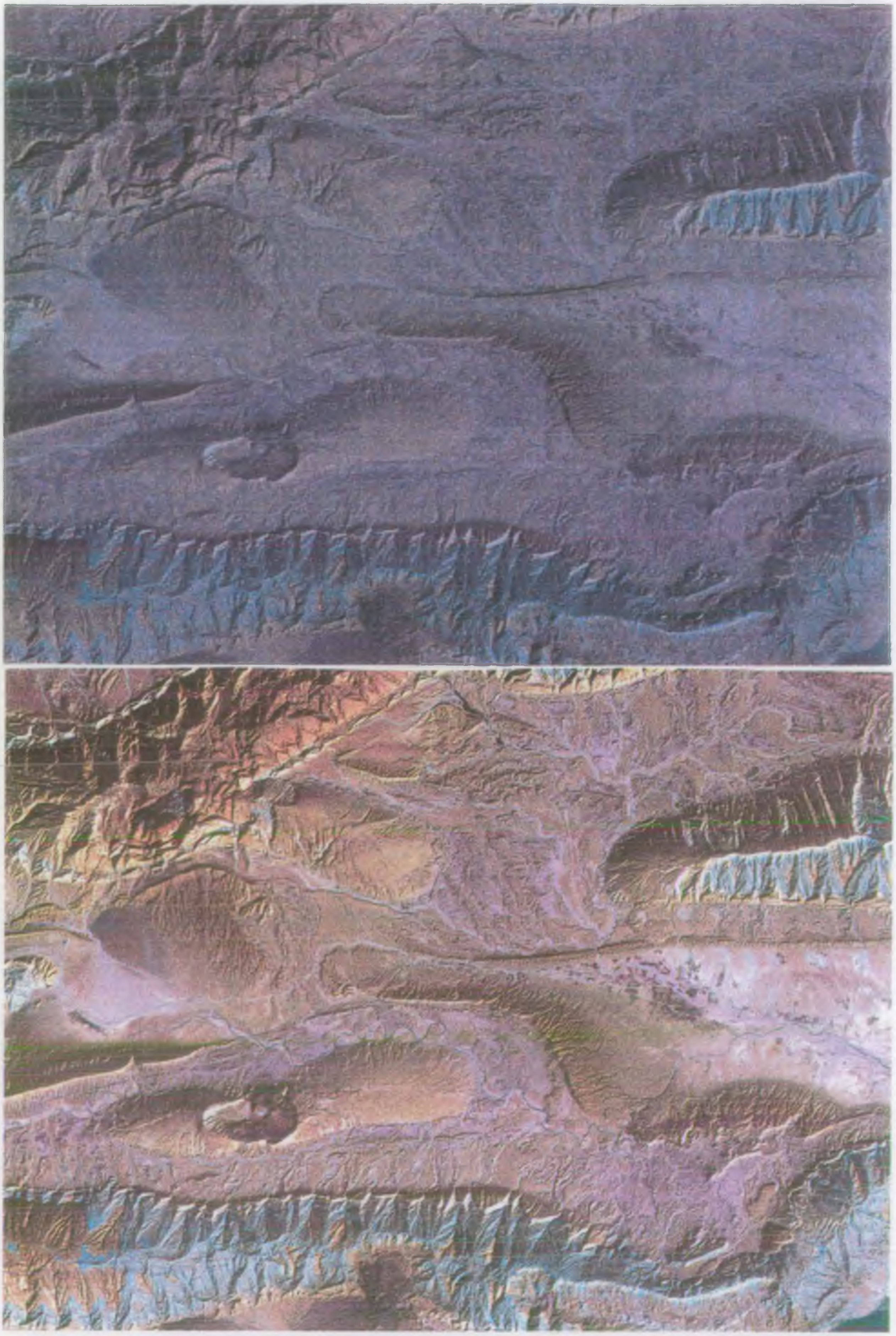


Figure 5.2 Raw and Contrast Enhanced Lansat TM Image

In order to understand this operation fully, it is necessary to introduce some statistical concepts, namely the idea of the *histogram* of an image. This is simply a "bar chart" showing how many pixels in the image have a given DN (called the *frequency* of that DN). Figure 5.3 illustrates this. In the unenhanced image, the histogram is squashed into a small region of the dynamic range, indicating low contrast. In the enhanced image, the histogram is stretched out across the whole range, greatly increasing the contrast, and making much more detail visible. This operation is called a *histogram stretch* or *contrast stretch*.

5.5.2 Look-Up Tables (LUT's)

One way of performing a contrast stretch is to generate a new data set, in which the DN of each pixel in the original image is replaced by the "stretched" DN, to generate the contrast-stretched image. The drawbacks of this method are twofold. Firstly, it means duplicating the dataset every time one wishes to apply a new stretch, which may quickly use up valuable disk space. Secondly, the original data is changed, which will alter the statistical characteristics of the image.

A better way of performing a stretch (or, indeed, any other histogram manipulation) is to generate a *Look-Up Table* (or LUT). This is, quite simply, a table which shows, for each DN value in the original image, what the stretched value is to be in the altered image. When the computer displays the image, it steps through each pixel, notes the pixel's DN, looks up what the corresponding stretched value should be, and displays that instead.

This approach circumvents the need to generate a new dataset every time a stretch is applied to an image, and preserves the data in its original form. It also saves on computation time, as simply "looking up" a value is far faster than computing it from a formula for every pixel in an image.

5.5.3 Generation of a LUT

This section is included for completeness, and to illustrate some of the points made in the preceding section. Referring back to Figure 5.4 shows the original (8-bit) image, and its corresponding histogram. It appears very dark, as its DN values are all in the range 0 to around 70. To improve the contrast, therefore, a stretch is defined such that

(a) all pixels with an original DN of 0 are given a stretched DN of 0.

(b) all pixels with an original DN of 70 or above are given a stretched DN of 255.

(c) all pixels with an original DN between 1 and 69 are given stretched DN's such that the new values are evenly distributed between 1 and 254.

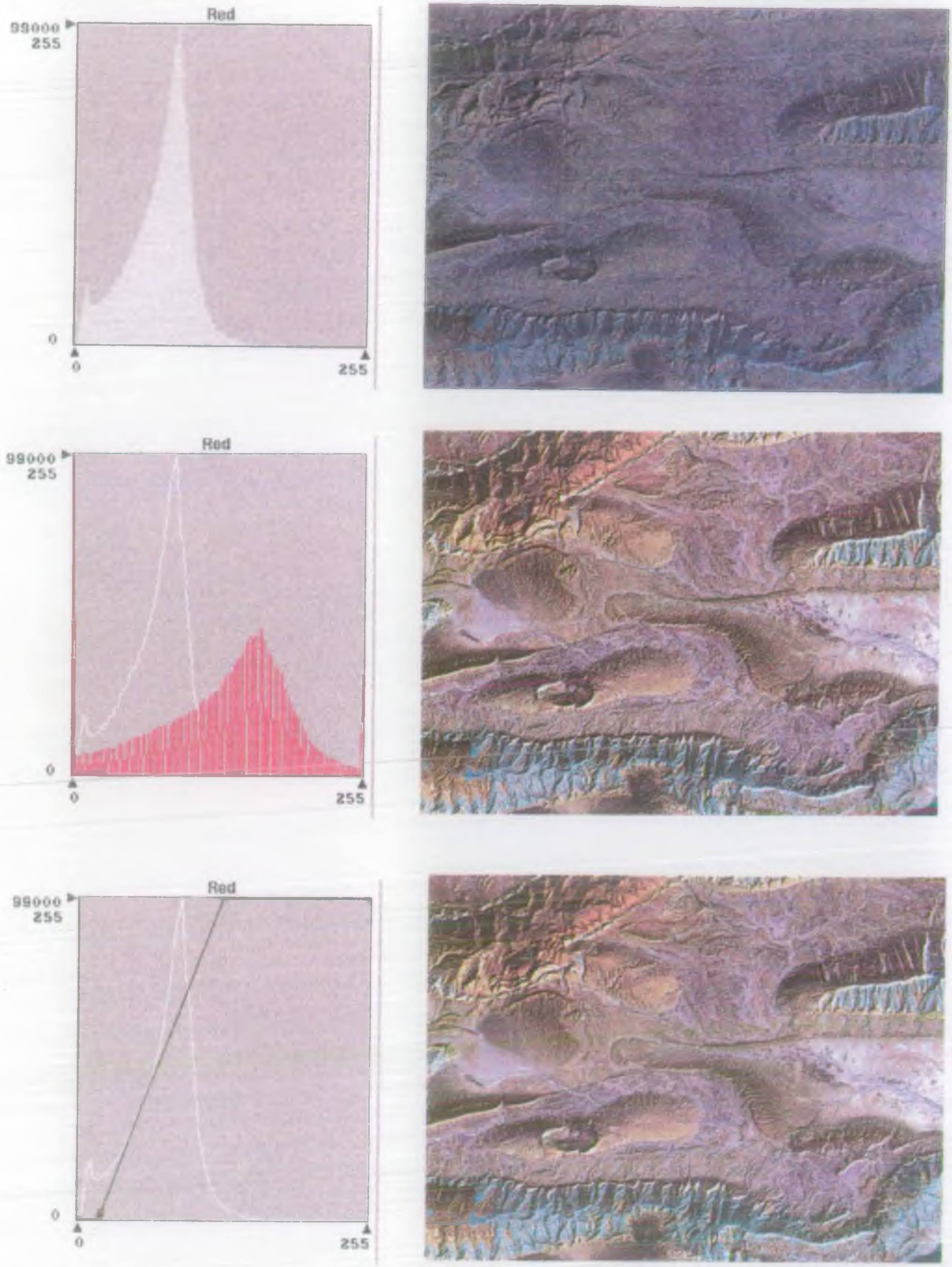


Figure 5.3 An Image Contrast Enhanced with Histogram

Original DN	Stretched DN
0	0
1	4
2	7
3	11
4	15
5	18
6	22
7	26
8	29
9	33
10	37
11	40
12	44
13	48
14	51
15	55
16	59
17	62
18	66
19	69
20	73
21	77
22	80
23	84
24	88
25	91
26	95
27	99
28	102
29	106
30	110
31	113
32	117
33	121
34	124
35	128
36	132
37	135
38	139
39	143

Original DN	Stretched DN
40	146
41	150
42	154
43	157
44	161
45	165
46	168
47	172
48	176
49	179
50	183
51	187
52	190
53	194
54	197
55	201
56	205
57	208
58	212
59	216
60	219
61	223
62	227
63	230
64	234
65	238
66	241
67	245
68	248
69	252
70	255
71	255
72	255
73	255
. . .	. . .
. . .	. . .
252	255
253	255
254	255
255	255

Figure 5.4 A Look Up Table (LUT)

Part (c) can be defined mathematically as a function;:

Stretched DN = (Original DN) x (256 / 70)

The stretched DN is rounded to the nearest whole number.

Applying these rules to each DN value in turn from 0 to 255 generates the LUT shown in Figure 5.4. The rules are said to *map* the original DN's into the stretched DN, and the function which generates the stretched DN's (represented graphically by the line on the histogram in Figure 5.4) is referred to as the *mapping function* or *transfer function*.

5.5.4 Other Histogram Manipulation

The stretch illustrated in the preceding section is known as a *linear* stretch, for obvious reasons. However, any mathematical function can be used to perform a stretch, for example, to force the histogram into a given shape. Some commonly used specialised stretches are described in the following sections.

The development of these techniques arises from statistical mathematics, and rigorous formal derivations of the functions involved are outside the scope of this discussion; for further information, the reader is referred to the mathematics texts in the Bibliography.

Histogram Equalisation and Histogram Matching.
The ideally contrast-balanced image would have an equal number of pixels in each DN value, so that the overall image appears neither bright nor dark. In this case, the histogram would be flat, with equal length "bars" in each DN value. Put slightly more mathematically, if an image has a dynamic range of 0-255 (256 values, 8-bit data), and contains *N* pixels, then for an ideally contrast balanced image, there should be *N*/256 pixels in each DN value.

Real remote sensing images, however, seldom if ever exhibit this quality. An approximation can be achieved by a particular kind of stretch called a *histogram equalisation* which stretches the histogram bars across the dynamic range such that the *average* number of pixels in each DN level, taken across the whole dynamic range, is equal to *N*/256

The practical application of this technique is in reducing the effects of illumination, e.g. from different sun angles. An extension of this is *histogram matching*, where the histograms of two images can be forced to have the same contrast balance (this is not the same as having the same contrast stretch). This is useful in, for instance, comparing two images of the same area, but taken under different illumination conditions.

5.5.5 Histogram Slicing

It is possible to define a *step* function, which will map original DN's in a specified range to a single DN in the stretched image, so "slicing" up the histogram The effect of this is to split up the image into regions of similar characteristics, e.g. for discriminating land from water. This can be used as a very simple form of classification, which is discussed in a later section.

5.6 GEOMETRIC CORRECTION

5.6.1 Warping

After correction for system effects, the image may still not be spatially accurate. For example, the scale may vary across the image, or the image may appear in the wrong orientation. Correcting this involves distorting the raw image through the application of a mathematical transformation, changing the position of individual pixels relative to one another. Figure 5.5 gives a diagrammatic representation of this process. The distortion can be quite simple, such as rotating the image through an angle, or complex, where the image is *warped* (also known as *rubber sheet transformation*) Where the aim of this correction is to display the image in a specific map projection, spheroid and datum, this procedure is also known as *geocoding*. Note that NRA aircraft flying the CASI-system are equipped with automatic roll correction systems, and a GPS. This information can then be used to automatically geocorrect the scene, with backup from ground control points as necessary, and considerably reduces the amount of operator interaction needed to perform the geocorrection.

5.6.2 Ground Control Points

To geocode an image, it is necessary to define a warping function, which will map the original image raster grid into the map projection. In effect, this converts the row and column co-ordinates of a pixel into a latitude and longitude on the map.

Warping functions can be simple or complex, depending on the desired degree of accuracy. In all cases, though, defining the warping function requires one to know some information about the geographic location of the image. This is best done through the selection of *ground control points* (GCP's). These are basically features in the image which can be identified, and for which the location in the desired map projection is known. The image is compared with a reliable map of the area (such as an Ordnance Survey map in the UK), and features visible in both the image and the map are identified; road intersections, runways, prominent coastline features and bends or junctions in rivers are appropriate features. The row and column coordinates of the feature in the image are noted with the latitude and longitude, or easting and northing, location of the feature from the map. When a sufficient

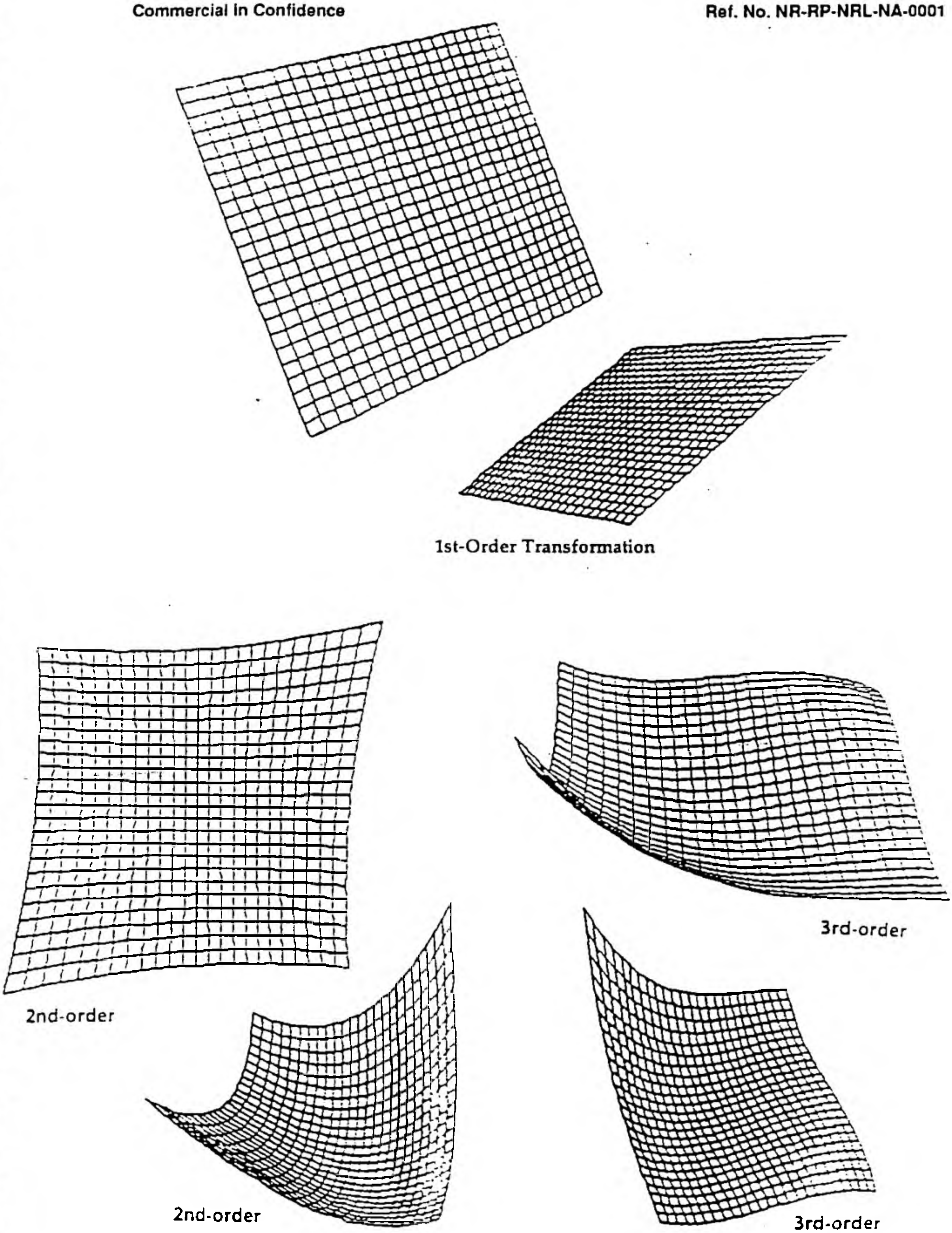


Figure 5.5 Example Effects of Warping a Square Raster Grid using First, Second and Third Order Transformation. (Source: Erdas Field Guide, 1993)

list of co-ordinate pairs has been established, a function to transform one to the other can be computed. This method can also be used to warp one image to another one, e.g. to directly compare two images acquired by different sensors, or from different platforms.

5.6.3 Resampling

When the image has been warped, the pixels rarely fit exactly into the geographically coded grid, illustrated in Figure 5.6. Some function must be defined for assigning DN values in the coded grid from the original DN values, a process known as *resampling*. This may introduce a further distortion in the image, but the effect on the accuracy of the geographical location of each pixel can be computed.

Where no maps are available, or insufficient GCP's can be identified, some geographical location information is generally computed from the orbital parametres of the satellite; generally, the latitude and longitude of the four corner pixels of the image, and of the centre pixel, are included in the header file of the image data tape. However, correction from GCP's is preferable, because this approach yields superior accuracy.

Geometric correction is basically intensive number-crunching, and as such, is ideally suited to a computing implementation. Almost all image processing packages will provide a capability for the selection of GCP's, the computation of a warping function, and the actual warping and resampling of the image. Note, though, that even for fast computers, warping a complete dataset can take from a few minutes to many hours, depending on the complexity of the warping and resampling functions.

5.7 FILTERING

Whereas histogram stretching and geocorrection alter the entire image as a single entity, it is possible to treat the image on a smaller scale, as a collection of individual pixels The statistical and spatial relationships within and between small numbers of pixels are then used to perform operations such as noise removal and edge enhancement. This process is known as *filtering.*

5.7.1 Smoothing

Smoothing is a simple method of removing noise. In its simplest form, it is accomplished by replacing the DN of each pixel with the average of the DN's of the eight pixels surrounding it. In this way anomalously high or low DN values, which are typically associated with unwanted noise, are "smoothed" out. The drawback of this approach is that fine detail is also smoothed out, and the image becomes somewhat blurred. Smoothing in this manner is also referred to as *low-pass filtering.*

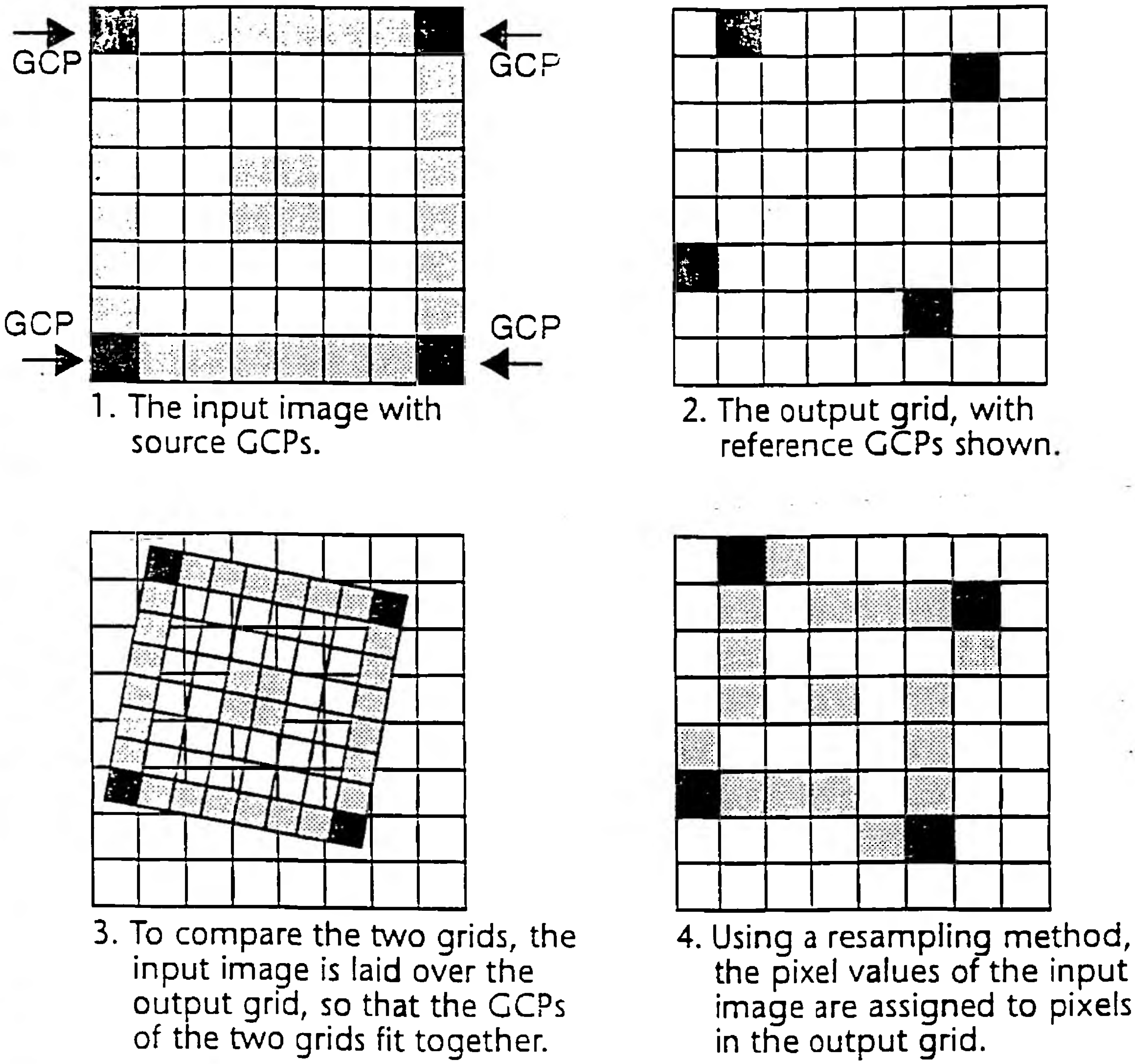


Figure 5.6 Resampling (Source: Erdas Field Guide, 1993)

5.7.2 Filters, Kernels and Convolution

An alternative way of looking at the averaging process is to imagine a 3 pixel x 3 pixel "window", in which each pixel has the value 1, overlaid on the image. Figure 5.7 illustrates this diagrammatically. The DN of each pixel in the image under the window is then multiplied by the value of the corresponding pixel in the window. The results are summed for all nine pixels, and then divided by the number of pixels in the window. This value then replaces the DN of the pixel under the centre of the window. In this particular case, it can be readily seen that this results in the average of the nine DN's. The process is repeated, centring the window on each pixel of the image in turn. In technical parlance, the window is known as a *kernel* and the process of applying it to the image is known as the *convolution* of the image with the kernel. Again, the reader is referred to the Suggested Further Reading for a full and rigorous discussion of these concepts.

While the convolution approach may appear at first sight unnecessarily complicated, it does allow more flexibility in considering other types of operation. For instance, each pixel in the kernel may be given a value, or *weight,* other than 1, resulting in a weighted average, which can help to preserve detail after smoothing The size of the kernel can be increased, which can smooth out excessive noise, at the cost of a higher degree of blurring. Alternatively, non-square kernels can be defined, to emphasise features occurring in a particular direction in the image. Kernel weights can be defined which will compute some statistical measure of the pixels under the kernel; for example the standard deviation of DN values, or the gradient of DN values in a particular direction. These measures all yield information about the scene which can be interpreted for a particular application.

5.7.3 Edge Enhancement

Many remote sensing applications require the detection of edges and linear features in an image, for instance, roads, runways or field boundaries. As mentioned above, a kernel can be designed which will yield a measure of the gradient of the DN values in the pixels under it, i.e. how much the DN values are changing from one side of the kernel to the other. Since an edge is generally defined by a sharp change in the brightness of an image, application of this type of filter will highlight or emphasise edges in the image. Further modifications can be incorporated to pick up edges in a particular direction.

Edge enhancement is also known as *high-pass filtering.*

5.7.4 Operations With More Than One Band

All the procedures described up until now operate primarily on one image, and only one band at a time. However, some of the real power of remote sensing lies in the interpretation of more than one band at a time. The true information content of a remote sensing image lies in interpreting all the bands of a multispectral dataset as a whole, and investigating the

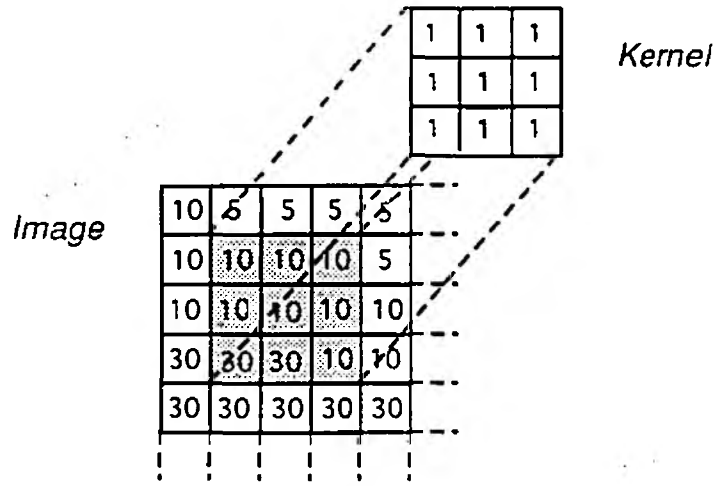


Figure 5.7 Principle of Convolution

relationship between the bands. A simple way of doing this is known as band arithmetic. This is performing arithmetical operations such as addition, subtraction, multiplication and division, and occasionally trigonometric functions, on corresponding pixels from each band image, to emphasise particular spectral features of interest.

A particular example of this is the derivation of the so-called *vegetation index*. This is essentially a quantity reflecting the amount of green vegetation present in each pixel. This number is based on the fact that healthy vegetation appears very bright in the near infra-red band, but rather dark in the red band. Subtracting an image of a scene in the red band from the near infra-red band can therefore yield an image where pixels with much vegetation have relatively high DN's and non-vegetated pixels appear with relatively low DN's. This is a useful way of delineating vegetation. A development of this is to divide the infra-red band by the red band, taking a so-called *band ratio*. This again yields high DN's where there is vegetation, and low DN's where there is little, but the absolute value of the DN can also be calibrated in terms of the amount of vegetation there. A further step again is the *Normalised Difference Vegetation Index* (NDVI), which is a more complicated combination of red and near infra-red bands, and can suppress some of the effects of illumination differences.

5.8 ADVANCED IMAGE PROCESSING TECHNIQUES

This section is included as a short introduction to some more advanced techniques which are available, and which exploit the multispectral information of a dataset. Again, the reader is referred to the Suggested Further Reading for comprehensive coverage of these topics.

5.8.1 Classification

It has already been mentioned that histogram slicing can be used as a simple means of classification, on the basis of the general brightness of darkness of a region in an image. More sophisticated classification can be done using all the bands in a multispectral dataset, using the statistics of the spectral signature of various features in the image to identify these features as "real world" entities. Using classification techniques, for example, it is possible to discriminate general land cover types (urban, agriculture, forest, water, etc.), identify crops growing in fields, and even determining the general health of the vegetation. The field of classification is an important one, as it is one of the primary means of extracting the most value from remote sensing imagery. Various techniques of classification are discussed further in Section 5.9.

5.8.2 Alternative Colour Representations: RGB and HSI schemes

The RGB composite has already been mentioned as one method of displaying the colour information of a scene. This idea leads to the concept of analytically describing colours in terms of the amounts of red, green and blue that make them up. For instance, a pixel which has a DN of 255 in red, 255 in green and 0 in blue will be pure yellow; thus yellow can be described as having RGB components of [255,255,0]. Extending this idea, one can think of the three colour components as defining a conceptual three dimensional space called a *colour cube,* or *colour space,* where the red, green and blue components of a colour are plotted on three axes at right angles to each other. Each available colour is then defined by its position within the cube. Figure 5.8 shows a diagrammatic representation of the RGB colour cube. Note that if the RGB components are all the same value, the result is a shade of grey.

An alternative way of describing colours analytically is the Hue Saturation Intensity (HSI) scheme. This is a more arbitrary scheme, but results in a description which more closely reflects the way in which the eye and brain perceive colours . As with RGB, each HSI component is described by a digital number from 0 to 255.

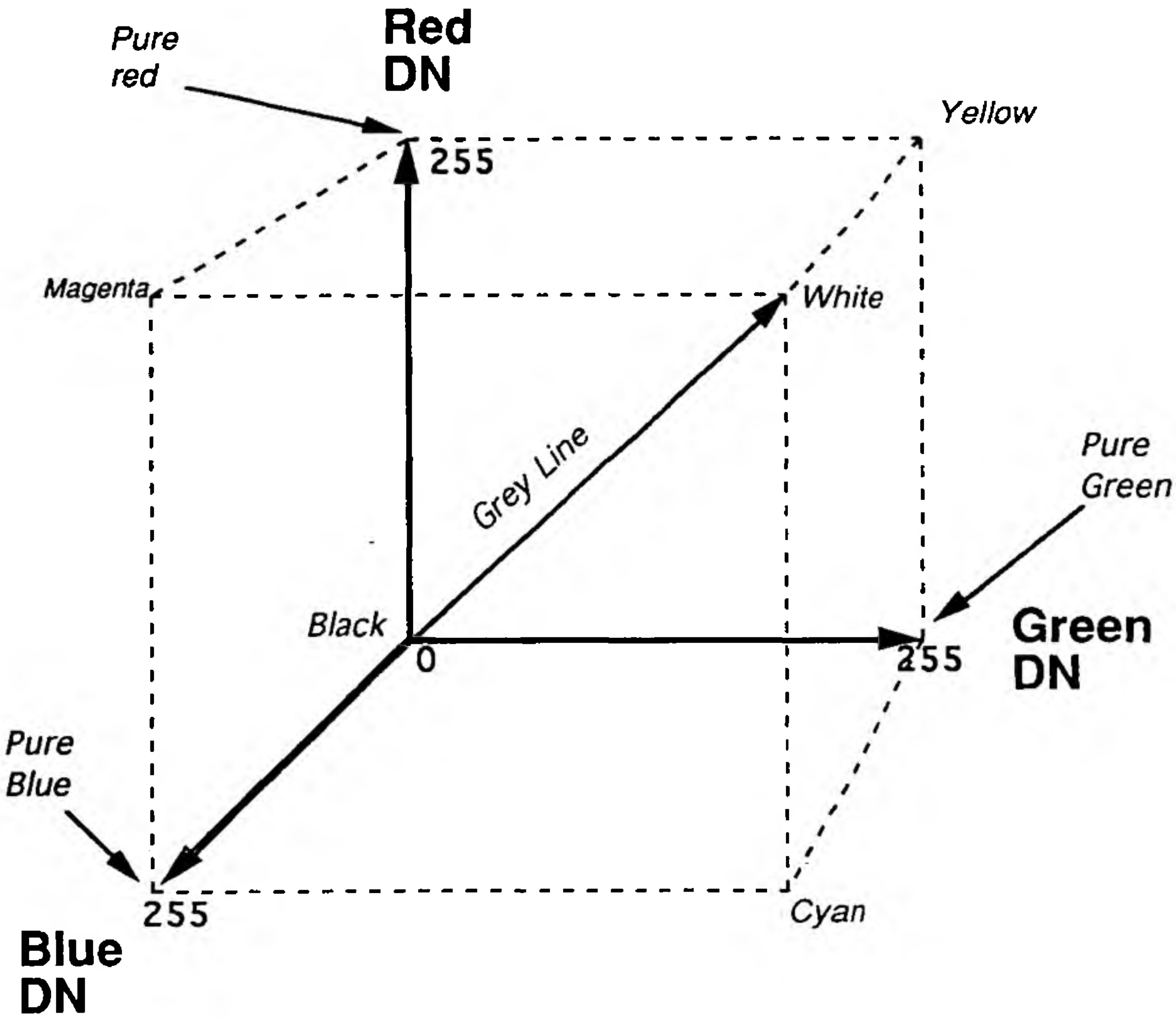
The Hue component of a colour is more or less self explanatory; it governs the basic colour. The meaning of a given DN in this context is entirely arbitrary, but convention is to assign pure red to be a Hue of 0, and go through the colour "wheel" of primary and secondary colours, through yellow, green, cyan, blue, magenta, and back to red with a Hue of 255. The Saturation component can be thought of as describing the "paleness" or purity of the colour, or alternatively, as the amount of white in the colour. A completely unsaturated colour, i.e. with a Saturation component of 0 is monochrome (white, grey or black) A completely saturated colour, .i.e. with a Saturation component of 255, is the pure colour. The Intensity component indicates the "brightness" of the colour. An Intensity component of 0 will always give black.

As with the RGB cube, the HSI component can also be thought of as forming a colour space, although in this case, the range of available colours forms a cone rather than a cube. Figure 5.9 shows this diagrammatically.

These techniques have two practical applications, in the removal of cloud shadows from imagery, and in "merging" datasets from different sensors.

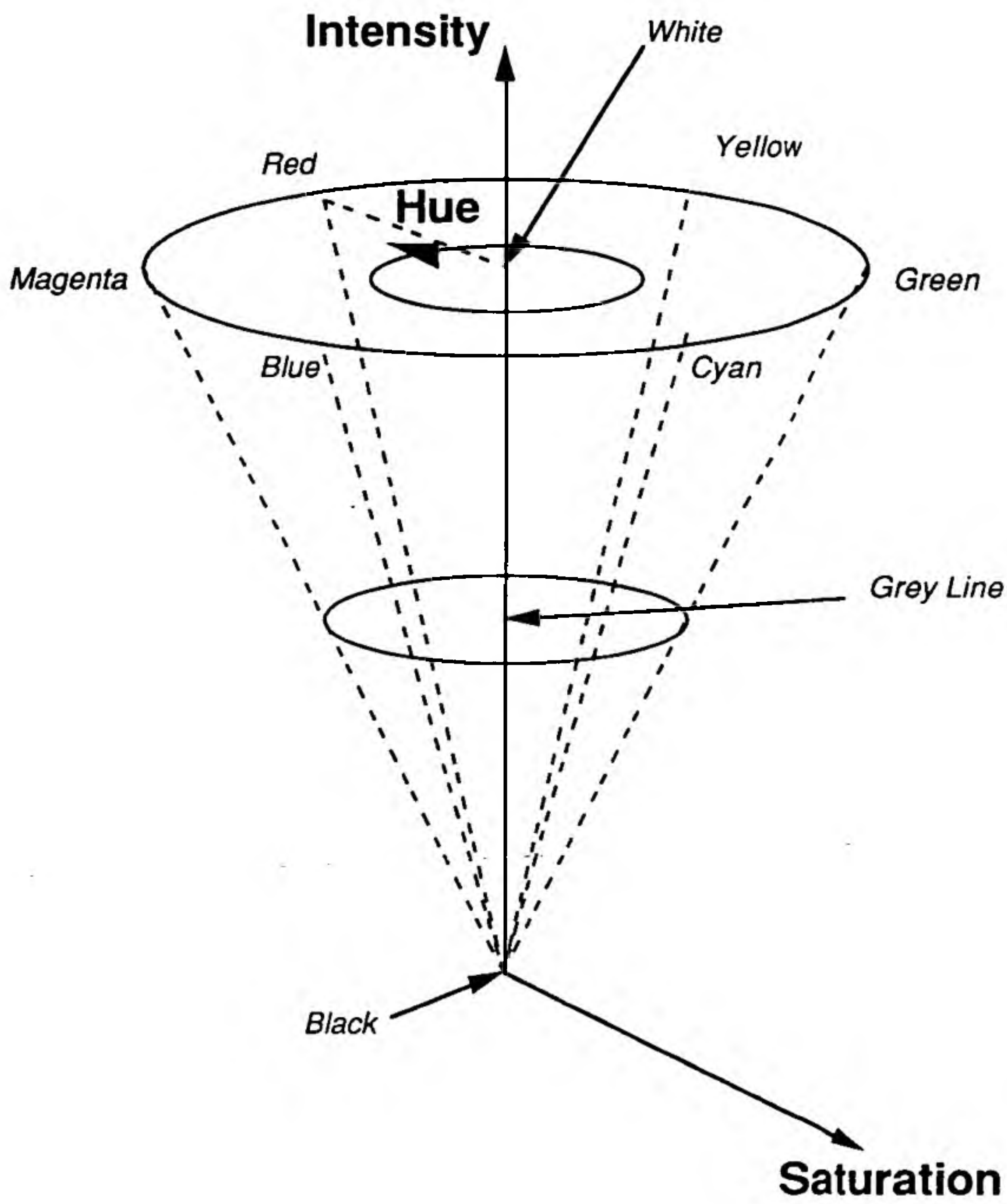
5.8.3 RGB-HSI Transformations

It is readily apparent that a given colour has two equivalent descriptions in RGB and HSI components, i.e. an RGB of [255,0,0] and an HSI of [0,255,255] both describe the colour of pure red. There is a mathematical equivalence between the two, so knowing the RGB components of a colour allows one to compute its HSI components, and move between the HSI and RGB "spaces". This mathematical relationship is known as an *RGB-HSI transform,* or a *colour space transformation.* As mentioned above, manipulating a colour dataset in the HSI description allows some rather subtle effects to be achieved. One disadvantage of this approach, however, is that only three bands can be operated on at a time.



This figure represents the conceptual three dimension colour "space" generated by plotting out the red, green and blue DN values making up a given colour. Each available colour is then specified by its position within the cube. The line joining the origin of the cube with the diagonally opposite corner shows where the red, green and blue components are all equal. This generates either black, white or a shade of grey, and so is known as the "grey line".

Figure 5.8 The Red-Green-Blue (RGB) Colour Cube



This diagram shows the colour space generated by the HSI scheme. Intensity is measured along the central vertical axis. Hue is measured by the angle measured clockwise around the Intensity axis from some arbitrary point (in this case, the Hue of pure red). Saturation is measured by the orthogonal distance away from the Intensity axis. These quantities are scaled in to the range 0 - 255 for digital representation. Any colour with an Intensity of 0 give black. As Intensity increases, the range of possible Saturation values also increases. All points along the Intensity axis (i.e. with a saturation of 0) give black, white or a shade of grey.

Figure 5.9 Hue-Saturation-Intensity (HSI) Colour Space

5.8.4 Merging of Datasets

The information content of digital data usually contains a trade-off between spatial resolution and spectral resolution, i.e. the number of wavebands. LANDSAT Thematic Mapper has a spatial resolution of 30 metres in the visible and reflected IR bands. SPOT Panchromatic sensor has a resolution of 10 m, but only has one waveband, i.e. limited spectral information can be gained from it. Using RGB-HSI transformation techniques, however, it is possible to merge a LANDSAT TM dataset with a SPOT Pan dataset. An RGB composite of the TM scene is produced, and then transformed into an HSI representation. The Intensity component of the composite is then replaced with the SPOT Pan scene, and the result is transformed back to an RGB representation. The effect is to produce a hybrid dataset with the 10m spatial resolution of SPOT with the spectral (colour) information of TM. This procedure requires the two datasets to be very accurately georeferenced, so that they overlay within one pixel.

5.8.5 Removal of Illumination Effects

The illumination conditions of an image, such as the angle of the Sun, and shadowing by terrain or clouds, naturally have an impact on the general brightness of the image. This in turn affects the RGB components of the scene. The Hue component in an HSI representation, however, is not affected by illumination (for example, a green surface is still "green" regardless of the amount of light falling upon it). Transforming between RGB and HSI representations therefore offers a way of removing or suppressing shadowing effects.

5.8.6 Multispectral Analysis

The HSI representation defines analytically the spectral character of a pixel. When an RGB colour composite is transformed into HSI representation, the result is three new digital images, where the DN's represent the Hue, Saturation and Intensity values, rather than Red, Green and Blue values. However, the HSI images are still, in the end, just digital rasters, and so can be histogram stretched; this can bring our features in the spectral information just as a histogram stretch can bring out contrast details in a conventional single band image. However, when the composite is transformed back into an RGB image for display, the result may be bright or arbitrary colours which may make visual interpretation difficult. Other techniques, such as producing composites of the Hue components of a sequence of colour composites (a HRGB composite) can aid classification and emphasise further subtle features of the spectral character of an image. This is particularly relevant to geological applications of remote sensing, e.g. distinguishing and mapping different rock types on the basis of their spectral signature.

5.8.7 Principle Component Analysis (PCA)

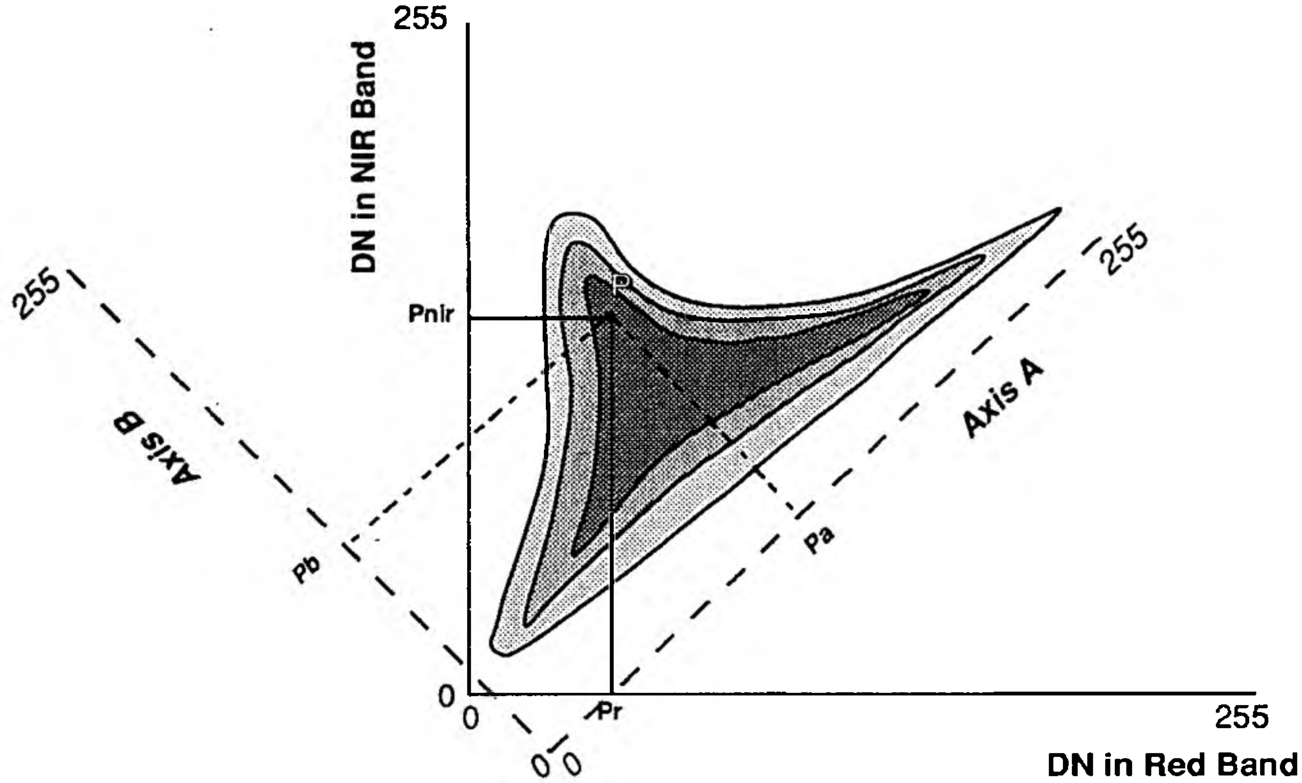
Principle Component Analysis is a statistical procedure which brings out spectral detail in a dataset in a similar manner to RGB-HSI transformations, but with the advantage that any number of bands can be used in the computations, as opposed to just three with colour composite techniques. The derivation of PCA is too complex to go into detail here, but its basic effect is to pick out the spectral features of a dataset which are correlated between bands, and separate them from those that are uncorrelated between bands, for example, features which are consistently bright or dark in every band of the dataset, as opposed to a feature whose brightness varies from band to band (this correlation is one way in which the information content of an image can be expressed). This, in turn, enables certain features, for instance, the "greeness" or "yellowness" of vegetation to be determined, or areas of different spectral character to be distinguished.

The Tasselled Cap Transformation
One application of this sort of analysis which has been used extensively is the "Tasselled Cap" Transformation developed for use in vegetation studies using LANDSAT MSS data. This procedure was developed by plotting scattergrams of MSS visible red band versus near infra-red band for images with a large proportion of vegetation. The resulting feature space tended to show a characteristic shape, as depicted in Figure 5.10 (the "tasselled cap" from which the name is derived). It is clear that the direction of greatest variation in the data is not parallel to the spectral band axes, but along a set of axes rotated at an angle to them, which are labelled A and B in the diagram. It was found that variation along the A-axis was correlated with the brightness of the soil beneath the vegetation canopy, while variation along the B-axis was correlated with the amount of green vegetation present. This leads to the alternative names for these axes as the Soil Line or "brightness" axis, and the Vegetation Line or "greeness" axis respectively. Performing the transformation is equivalent to scaling the brightness and greeness axes into the range 0-255. The DN of each pixel in the scatter plot is calculated on the new axes, and new digital images constructed. The DN value of each pixel in these images then reflects the soil brightness and vegetation greeness in the scene at that point.

Plotting the visible green band as a third axis at right angles to the other two (effectively coming out of the plane of the page in the diagram) creates a three-dimensional feature space in which the pixels occupy a volume, with an equivalent third new axis. This axis has been related to the "yellowness" and health of the vegetation.

5.8.8 Fourier Transform Analysis (FTA)

Fourier analysis is a way of looking at the spatial frequencies of an image, i.e. how quickly the DN value is changing from one point in an image to another. In effect, FTA converts an image into a representation of the spatial frequencies present in that image. Since noise tends to be associated with high spatial frequencies, the noise in an image will appear as a



This figure illustrates the typical feature space generated from an image rich in vegetation, with the characteristic "tasselled cap" shape to the distribution of pixels. The shading reflects the number of pixels present at that point in the feature space. Axes A and B are drawn parallel to the directions of greatest variation in the data. A pixel at ***P*** has DN vales P_r in the red band and P_{nir} in the near infra red band. In the transformed axes, it has DN values P_a and P_b; these will appear in images of soil brightness and vegetation greeness respectively.

Figure 5.10 Principle of Tasselled Cap Transformation "spike" or bright spot at a particular point in the frequency image. This spike can be edited out, and an inverse Fourier transform applied to convert the spatial frequency representation back into a visual image, but now without the noise. This is also an efficient method of removing systematic interference in an image, such as the so-called sixth-line stripe effect seen in some MSS images.

5.9 CLASSIFICATION TECHNIQUES

5.9.1 Introduction

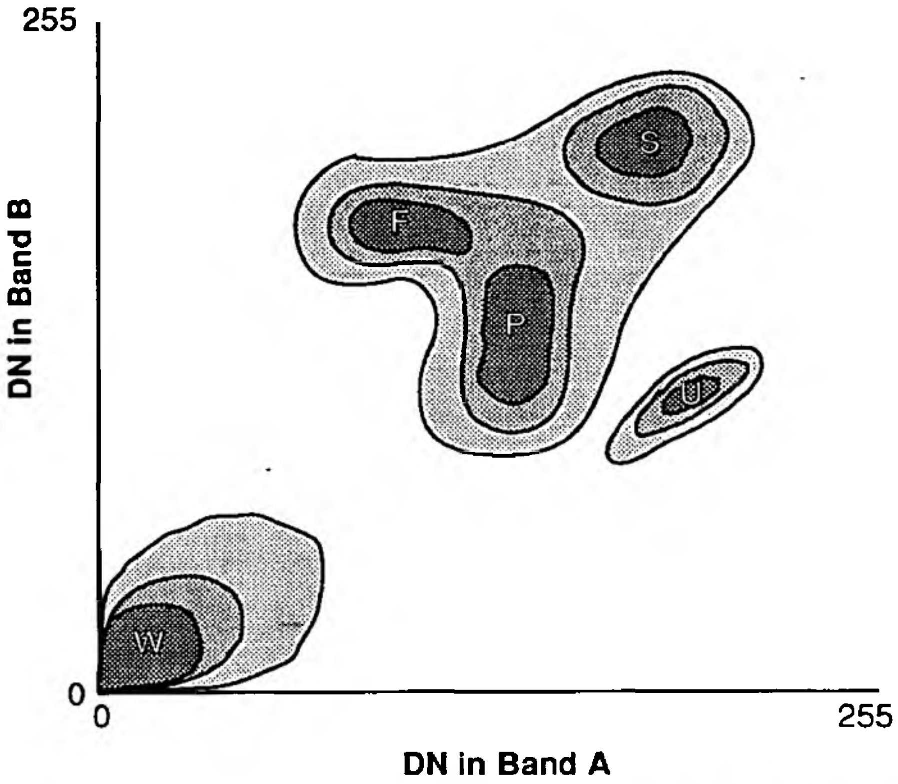
As mentioned in Section 5.8.1, classification is the general technique of identifying and discriminating different features in an image in terms of the features they represent in the real world. For example, this might include the identification of forested areas in an image, or the discrimination of different crop types. The main source of information for these procedures comes from the spectral information of a multi-waveband image.

The general principle of classification is shown in Figure 5.11. Suppose one takes two bands of an image. For each pixel in the image, its DN in Band A is plotted on the *x*-axis of a graph against the DN in Band B on the *y*-axis. The resulting diagram is known as a *scatter plot* or *scattergram*, wherein the pixels will generally fall into two or more extended groups or clusters, corresponding to different types of ground cover. Classification in this case therefore, involves dividing up these clusters in this so called feature space, deciding what each cluster represents, and assigning each pixel in the image to one of the classes. There are a great number of methods, of varying complexity and accuracy for achieving this, usually by consideration of the statistical relationships within and between the clusters.

The example illustrated in Figure 5.11 uses just two bands, but the general principle can be extended to as many bands as there are in the dataset. Visualising the process then becomes rather difficult, but in general, the more bands that are used, the more classes can be discriminated, and the greater the accuracy of the classification becomes. For instance, it is possible to discriminate agricultural land from urban land in an image, and to further discriminate different types of crop, on the basis of its so-called *spectral signature.*

To exploit classification to the full, some element of *ground truth* is needed. This is simply some prior knowledge of what is in the scene, so that the classes distinguished by the classification process can be interpreted as ground cover. This leads to two broad approaches to classification:

Unsupervised Classification.
In this approach, the feature space diagram may be divided up purely on the statistics of how the clusters form, and without any reference to ground truth, although ground truth may be needed to decide what each statistical cluster represents.



This figure shows a generalised feature space that is typically obtained from an image containing areas of water, vegetation and urban development. The shade of grey reflects the number of pixels that have been plotted at that point. The classes representing water pixels (W) and urban pixels (U) form well defined and spectrally distinct clusters that are easily separable. The vegetation pixels form another group, within which three further clusters can be distinguished: soil (S), forest (F) and pasture (P). These classes are less distinct and overlap to some degree.

Figure 5.11 Principles of Classification

Supervised Classification
Supervised classification uses ground truth to both define and verify classes. Pixels are taken from ground truth areas, which are known to be of that class, e.g. certain crop type, urban areas, water, etc. These representative pixels are plotted in feature space, and the classes defined according to initial clusters so formed. The remaining pixels in the image are then allocated to one (and only one) of the clusters on statistical criteria. This method is further discussed in Section 6, in the Case Study on assessment of likely sources of agricultural pollution.

5.9.2 Linear Mixture Modelling

One recurring problem with classification algorithms of all kinds is that of "mixed" pixels; that is, a pixel in which more than one kind of ground cover type is present. This is, in fact, a significant problem, since in "real" remote sensing images, the majority of pixels will be mixed to some degree. For instance, a pixel in a forested area will contain radiance not just from the forest canopy, but also from the ground beneath, perhaps from the branches and trunks, and also some radiance from atmospheric effects. Also, ground cover types, particularly natural ones, are seldom completely homogeneous, and rarely have sharp boundaries between them. Such regions are more likely to gradually merge into each other, producing a high number of mixed pixels, with varying proportions of each cover type in the intermediate regions.

Mixed pixels are problematic for two reasons. Firstly, they may degrade the accuracy of the classification, since conventionally, each pixel is placed into one, and only one, of the available classes. If a pixel in fact contains more than one class, then it will over-represent the class it is put into, and under-represent the classes which is not put into, but which nevertheless are present. This will cause errors in, for example, crop yield or area calculations. Secondly, the spectral signature of a mixed pixel may not be sufficiently similar to the spectral signatures of the classes for it to be placed into any of the classes, or perhaps into a completely erroneous class. In any case, it will degrade any measure of accuracy or confidence in the classification.

The method of mixture modelling can help to overcome these deficiencies by "unmixing" such pixels, and estimating the proportion of each class present. This is done by assuming that the spectral signature of such a mixed pixel is composed of the spectral signatures for each class present in the pixel, summed in proportion to the fraction of the pixel containing that class.

For example, suppose a particular pixel contains 25% forest and 75% water. With the assumption above, the spectral signature of the whole pixel would be expected to be 0.25 times the spectral signature of forest plus 0.75 times the spectral signature of the water.

This idea can be generalised to any number of bands and classes, and may be expressed in matrix notation as:

$$\mathbf{x} = \mathbf{M}\,\mathbf{f}$$

where **x** denotes the spectral signature recorded from the mixed pixel, **M** is a matrix specifying the signal recorded from each class in each band (referred to in this context as the end member spectra), derived possibly from ground truth and **f** is a matrix specifying the fraction of the pixel covered by each class. The task is then to invert the relationship and deduce **f** given **M** and **x**. The reader is referred to the Suggested Further Reading for detailed mathematical treatment of this problem.

5.9.3 Contextual Classifiers

Most standard classification algorithms work on a "per pixel" basis, i.e. examining the spectral signature of each pixel in isolation, and attempting to assign it to one of the specified classes. This method rests on a number of assumptions concerning the statistics of the spectral signatures, which, in real life, do not generally hold. As mentioned above, the presence of mixed pixels is an important problem. Contextual classifiers attempt to circumvent this problem by considering pixels collectively, grouped into higher level features such as fields, roads, etc. The context of these features is then used to classify them in addition to the spectral information. Context can include the location of the feature in relation to other features in the image, its texture, and perhaps its geographical location. This process (also known as *image segmentation*) mimics, to a certain extent, the intuitive way in which a human observer interprets images. For example, agricultural fields are generally characterised by straight edges, rough texture, and are generally found grouped together with similar agricultural features.

5.9.4 Classification by Artificial Neural Networks

A recent advance in the field of classification is the application of Artificial Neural Networks (ANN's), commonly referred to as *neural nets.* Again, a full discussion of neural nets is too complex to be included here, but the basic principle is that the net is a computer architecture which combines a large number of simple processing units, arranged in "layers", which mimic the way in which biological systems store and process information. Neural nets have the property that they can "learn" to recognise quite complex patterns. Once trained with appropriate ground truth data, the neural net can partition up the feature space of a given image in a much more flexible manner than conventional statistical techniques.

5.9.5 Hyperspectral Processing

Hyperspectral data has already been mentioned in relation to imaging spectrometer type instruments (see Section 1.2.2). The ability to construct an "image cube" dataset, where the scene is imaged in a large number of bands and a high resolution continuous spectral signature for each pixel in the image can be derived, has immense implications for applications such as classification, land use, and geological discrimination. One method of analysing these data is by building up a library of spectral signatures from samples of different rock types or vegetation species. Signatures from the hyperspectral dataset can then be compared with these library spectra, and discrimination and classification performed.

One problem with this method is the sheer volume of statistical computations required to operate of several hundred bands at once (note that the volume of data, in terms of number of bytes, is not generally a problem, since the images concerned are usually of small dimensions). Also, the effect of mixed pixels will be more pronounced with the greater spectral resolution of the hyperspectral dataset. As such, all the advanced techniques described in the preceding few sections (mixture modelling, neural nets, pattern recognition, etc.) will be more important than ever in utilising hyperspectral data to the full.

5.9.6 Classification Summary

The field of classification is an important one for fully utilising the capacity of remote sensing imagery, and is still the subject of much research. Many image processing packages implement conventional supervised / unsupervised classifications, such as the ISODATA clustering algorithm. Neural nets, contextual classifiers and mixture modelling are also beginning to be available on such systems; these new areas are still under investigation.

However, as with most things, no one approach will give optimum performance 100% of the time. For instance, while a neural net classifier offers flexibility in interpreting complex images, some "real" images do exhibit feature spaces with easily separable classes; in this case, a simpler clustering algorithm may be faster and perform just as well. Also, even the most sophisticated neural net classifier will produce poor results if the ground truth data used to train it are poorly chosen. The most appropriate approach will vary from case to case; the availability of advanced techniques simply increases the armoury available to image interpreters to tackle a particular problem.

5.10 ATMOSPHERIC CORRECTION

5.10.1 The Problem of Atmospheric Effects

Although the atmosphere appears by and large transparent to the human eye, it does have a considerable effect on any electromagnetic radiation passing through it. At any instant as the remote sensor scans the Earth below it, the sensor observes an area of the Earth's surface called the *Instantaneous Field Of View* (IFOV). Each IFOV reflects a certain amount of radiance back through the atmosphere, and it is this quantity that the remote sensing interpreter is interested in. However, that radiance is only one component of the radiance that arrives at the remote sensor above the atmosphere, and is recorded in the image. The atmosphere interferes with the signal in three ways:

- by scattering radiance from the IFOV away from the sensor.
- by scattering radiance from other sources apart from the IFOV into sensor
- by absorbing and re-emitting some proportion of the radiance (attenuation)

The process of removing or compensating for these unwanted effects is called *atmospheric correction*. This correction is significant. Scattering effects tend to be strongly wavelength dependant, affecting the visible blue bands the most. In these bands, scattering can account for up to 90% of the measured radiance. Some of the radiance recorded by the sensor may not even be reflected from the ground, but just have been scattered through the atmosphere, and into the sensor (this effect is known as *path radiance*). The overall effect of this on a blue band image is to make it appear blurred and hazy, particularly at the edges, where the radiance has the furthest distance (or *path length*) to travel through the atmosphere. The absorption and re-emission affects the thermal and long wave infra-red bands the most. In any accurate determination of absolute sea surface temperatures, for example, this effect must be accounted for.

5.10.2 Correcting for Atmospheric Effects

Unfortunately, atmospheric correction is not a straightforward process, especially in the visible and near infra-red. The amount of radiance involved is strongly dependant on the state of the atmosphere between the sensor and the IFOV, particularly the amount of aerosols (small particles) present. Aerosols include dust and smoke, water droplets, ocean spray, even large clusters of molecules from various sources. As might be expected, the concentrations of these entities vary widely and, to a certain extent, unpredictably, from place to place on the Earth's surface. Numerous methods have been, and continue to be, developed to address this problem. Many of these are only practically implemented using image processing techniques outlined in this section, for example, by taking band ratios, or some other more complex combinations of bands.

Atmospheric correction of optical data

Optical data here is taken to include multispectral image data acquired at visible and near infra-red wavelengths for applications such as water quality determination or classification.

A simple approach is to simply relate ground truth directly to the remote sensing data, establishing a regression relationship calibrating the DN in a given pixel directly in terms of the measured ground truth quantity. This contains an implicit atmospheric correction, and has the advantage that it is straightforward to implement. However, the results are highly scene-specific, and the process would have to be repeated for each image under consideration.

Another common approach which is relevant to studies of water bodies, is to make use of the fact the water is almost completely absorbing at near infra-red wavelengths, combined with a mathematical model of the atmosphere. Pixels of clear water, identified either through ground truth or other criteria, are identified in the NIR band image of the scene. It is assumed:

- No NIR radiance is emerging from the water
- Any radiance recorded from the identified pixels is due to atmospheric scattering effects
- It is possible to extrapolate the amount of scattered radiance in one band to another band (the *Ångstrom Law*)

The amount of NIR radiance recorded from these selected pixels is then taken to be atmospheric scattering, and this amount is extrapolated into other bands. The amount of radiance can then be corrected for in other bands.

The validity of these assumptions varies from case to case, and care must be taken in applying them. However, they are reasonable assumptions in the majority of cases. A more rigorous approach involves measuring the characteristics of the atmosphere at the time the image is acquired, for example, by photometer measurements of sunlight. Atmospheric scattering can then be explicitly inferred form these measurements, and corrected for in the remote sensing data. These measurements can form part of a ground truth collection campaign.

A still more rigorous approach is to use a mathematical model of the atmosphere, and use radiative transfer theory to calculate explicitly the amount of radiance scattered into the sensor in each band. Certain "standard" model atmospheres exist for a number of different environments, such as urban, coastal, deep ocean, and so on (for example, the LOWTRAN series of codes developed by the US Airforce Geophysics Laboratory). While this is perhaps the most accurate approach, it can also be laborious, and may use an inordinate amount of computing time. The accuracy also depends on how well the model reflects the actual state of the atmosphere at the time that the image was acquired.

Data acquired from airborne instruments is not immune to atmospheric effects, since most of the aerosols responsible for scattering effects are concentrated in the lowest few kilometres of the atmosphere.

Atmospheric correction of thermal data
This is particularly relevant to derivation of sea surface temperature; for instance, from AVHRR data. This is perhaps slightly less complex than the case for optical data, since scattering effects are negligible at thermal infra-red wavelengths; the physical process of absorption and re-emission by the atmosphere dominate.

Many sensors intended for this application have been designed with the "multi channel / multi look" philosophy. This is consists of making two measurements of the same area of sea under varying conditions.

The AVHRR sensor exemplifies the multi channel approach; the so-called *split window.* AVHRR has two thermal infra-red bands, one centred on 10.8 μm, the other on 11.4 μm. The absorption properties of the atmosphere at these wavelengths are slightly different, so a comparison of measurements at these wavelengths allows the atmospheric component to be accounted for.

The ATSR sensor, on the other hand, uses the "multi look" approach. It observes both the area at the nadir, directly beneath the satellite, and a point behind the nadir, along the track of the satellite. The effect of this is to view the same area of sea from two different angles, effectively with two different path lengths through the atmosphere. The variation of measured radiance with path length can then be inferred, and the radiance that would be measured with zero path length (i.e. no atmosphere present) can be extrapolated.

5.10.3 Summary

Atmospheric correction is an important and complex problem. The most important and problematic area is the correction of optical data for the scattering effects of aerosols. This is mainly due to the wide variation in composition and concentration of aerosol particles from place to place on the Earth's surface. Many algorithms have been developed for different sensors, and for use in different conditions and parts of the world. As with retrieval algorithms (discussed in Section 5.11), there is no universal atmospheric correction algorithm, although it is quite possible to set up a correction procedure based on a particular location and sensor. The optimum approach will depend on the specific circumstances of each application.

5.11 RETRIEVAL ALGORITHMS

A topic related to atmospheric correction is that of *retrieval algorithms.* This term describes the mathematical process by which a multi spectral or thermal data set is interpreted to yield quantities such as chlorophyll concentration, sea surface temperature or sediment load. Much of the work in this area has been done in relation to CZCS data, and the algorithms continue to be adapted an re-assessed for use with the forthcoming SeaWiFS sensor.

5.11.1 Analytical Composition of Water Colour

The colour of a water body can by measured analytically by the ratios of radiances emerging from the water at different wavelengths throughout the visible and near infra-red regions of the spectrum. This quantity is termed the *water-leaving radiance*, and can in turn be interpreted in terms of the nature and concentration of material suspended in the water. For instance, a ratio of the water leaving radiance at 0.44 µm (blue) to the radiance at 0.56 µm (green) can be correlated with chlorophyll pigment concentration.

Material found in water bodies can be divided into three types:

- Chlorophyll and related pigments
- Particulates of a non-biological nature, such as sediment, outwash from river systems, man-made pollutants.
- Dissolved organic material from a variety of sources (so-called *gelbstoffe* or "yellow substance").

Various mathematical models have been constructed to predict how varying combinations and concentrations of these materials affects the water-leaving radiance.

On this basis, water bodies are commonly divided into two types:

Case 1 Waters
Waters containing living algal and phytoplankton cells, together with associated debris and derived yellow substance. These waters tend to be found in the deep ocean, far from land, and have optical properties dominated by chlorophyll and related compounds.

Case 2 Waters
Waters containing all or some of the following: suspended sediments, particles from river or glacier run off, yellow substances of non-marine origin, man-made pollutants in particulate or suspended form. Some or all of the constituents of Case 1 waters may also be present. Case 2 waters are typically found in coastal, estuarine and river environments, and have optical properties dominated by the materials suspended in them; generally sediment, yellow

substance, or a combination of the two.

5.11.2 Methods of Retrieval

As with atmospheric correction, there are both theoretical and empirical routes to establishing a retrieval algorithm. Indeed, atmospheric correction is an important part of such a procedure, because of the increasingly dominant effect of atmospheric scattering in the visible green and blue wavelengths.

In Case 1 waters, the situation is comparatively straightforward, since there is a limited range of substances present, all with similar optical characteristics, and, indeed, many of the operational chlorophyll concentration algorithms developed for CZCS can be adapted for use with other sensors. However, it is more likely that NRA applications will be dealing with Case 2 waters in the coastal, estuarine or lacustrine environment. Here the situation is rather more complex owing to the sheer variety of substances which could be present. The sediment component of suspended material, for instance, will depend entirely on the geology of the nearby coastline or area, which in turn will influence the spectral signature of the water.

Currently, there are no entirely general or theoretical models or algorithms which can be used in Case 2 waters, as the same radiance ratio value may result from many different combinations of material. The most straightforward way of conducting operational ocean colour surveys is therefore by the collection of water samples[1], analysing their contents, and relating this empirically to the remote sensing radiance values, usually through a regression relationship of the form:

$$\log C_{ij} = a + b \log R_{ij}$$

Where C_{ij} is the parameter to be measured (e.g. chlorophyll concentration in mg m^{-3}), R_{ij} is the ratio of radiances in wavebands i and j , and a and b are constants derived from the regression process.

As mentioned in the preceding section, this contains an implicit atmospheric correction. Some processing for atmospheric effects may still be needed, however, to bring out fine structure or detail in the data set. Again, the disadvantage of this method is that it produces an algorithm that is only valid for one scene.

If some prior knowledge of the area is available, for instance, in a estuary where tidal effects such as sediment concentration fronts are well documented, it may be possible to build up a model of the region which can be used to calibrate the remote sensing data. It may even be

[1]This is effectively a form of ground truth. However, in this context, ground samples are known more appropriately as "sea truth".

possible to construct a complete mathematical model of the water contents and the atmosphere above it. The contents of the water and the parametres of the atmosphere can then be varied iteratively, and the resulting radiances computed, until the modelled radiance agrees with the remote sensing data. This is more rigorous, but may also be very computationally intensive. It may be preferable to accept a greater degree of error, for a faster and less cumbersome approach.

5.11.3 Summary

The subject of retrieval algorithms and the interpretation of ocean colour has been the subject of much research and investigation since the early 1970's. For Case 1 waters in the deep ocean, standard algorithms have been developed for the retrieval of chlorophyll concentration and related parametres which are reliable. The situation of Case 2 waters is still not so clear, owing to the widely varying content and conditions in Case 2 areas. In these situations, it is probably not possible to construct an accurate, reliable, generic algorithm which be applicable to all instances. The usual procedure for remote sensing surveys of Case 2 waters is to correlate the remote sensing data with surface measurements of sea truth and atmospheric parametres, developing a scene specific algorithm in each case.

5.12 GEOGRAPHIC INFORMATION SYSTEMS (GIS)

5.12.1 Introduction

A GIS is a computer database which stores, analyses, manipulates and displays spatially referenced data. A less formal definition might be that a GIS is a computer system capable of storing and using information describing places on the Earth's surface. GIS is mostly widely thought of as providing digital maps. While this is one function of such a system, a full GIS provides much more capability than just displaying map data. It provides a medium where information from numerous different sources can be integrated, analysed and interpreted. Remote sensing imagery might be just one of these sources, and a GIS is an important tool in utilising the full information content of a remote sensing image.

5.12.2 Spatial Data

Spatial data is information that is referenced by its location. Examples might be a network of roads, the postcode location of a building, the type of vegetation present in an area. Examples for reference systems might be the row / column co-ordinates of a particular pixel in an image, the Ordnance Survey grid reference of a building, or the latitude / longitude of a point on the Earth's surface.

A GIS differs from a "conventional" database or spreadsheet in that a GIS permits spatial operations or analyses to be performed on the data. For instance, suppose a dataset exists giving the location of all the NRA facilities in the U.K., along with their Ordnance Survey grid references and the number of people working at each location, broken down by grade. Computing the average number of people working at each site is an *aspatial* operation; it does not use the geographic information of the grid references. On the other hand, computing the number of technical staff in Wales, or how many facilities lie within 100 km of each other, does require spatial information; this is the kind of query that a GIS can answer.

In particular, a GIS allows a spatial dataset to be queried in five important ways:

- *What is at a given location?* As mentioned previously, a GIS allows a location to be specified in many different ways; not just in formal geographic reference systems, but also as postcodes, Parliamentary constituency, etc.

- *Where is a given feature?* This query is answered by finding locations which fit a set of criteria, for instance, the locations of land parcels within 500 metres of a main road, more than 1 km from residential housing, containing low-grade agricultural land.

- *What has changed over a given period of time?* This can help establish trends, for instance, the rate at which urban areas are expanding, or how much coastal land has been lost to erosion.

- *What spatial patterns exist in the data?* Answering this query employs the analytical power of a GIS; for instance, examining the variations in vegetation health in a region, and seeing whether poor vegetation is correlated with local industrial zones. This might point to excessive pollution, and perhaps give an indication of its source.

- *Modelling - what happens if something changes?* This is a common use of GIS systems, for example to try and predict what is likely to happen if a new road is added to a network, or how the construction of a dam might alter the water system of an area.

5.12.3 Integrating Different Datasets

Part of the power of a GIS lies in its ability to link data from different sources together, producing "value added" datasets. Data can be linked in a variety of ways, depending on the nature of the information they contain. In all cases, the common reference system which allows the datasets to be related is the geographic or spatial component of the information.

In most cases, particularly where remote sensing data is input to a GIS, linking datasets is equivalent to laying a series of maps on top of each other, and noting the different combinations which occur. Each "map", or dataset, generally contains information on a specific topic, such as crop yield and soil type

5.12.4 Description Of Spatial Data Within a GIS

Raster and Vector

There are two important ways of storing spatial data. A *raster* is similar in concept to a digital image, being an array of cells, each of which contains a value. A raster in a GIS context is more generalised than an image raster, since the values held in each cell can reflect any information, or *attribute*, such as geology type, land use, and so on. This common ground between digital remote sensing images and GIS datasets leads to a natural affinity between the two areas.

The second method of describing spatial data is by means of *vectors.* A vector is basically a line in space (also referred to as an *arc*) defined by two end points (called *nodes*). These arcs and nodes can represent features such as roads, field boundaries, runways and so on. The arcs can further be assembled into *polygons*, which can represent the fields themselves, or land use parcels, and so on.

Which description is most appropriate, raster or vector, depends mainly on the type of information and the format which it is available in. Areal information, such as geology, vegetation cover, land use, is generally more conveniently handled in a raster description, whereas features that are naturally expressed as points or lines (for example, roads, railway lines, positions of features such as wells or power line pylons) lend themselves to a vector description. When classification is undertaken, it is often necessary to convert raster areal information to vector format, in order to attribute the different classes in polygons. Transferring between the two descriptions is not always an easy process, and GIS systems (such as ARC/INFO) will be able to handle both types of information and overlay one on top of another.

Points, Lines, Polygons and Attributes

Within the GIS, raster information is stored in the same way as a digital image. Vector information is stored rather differently. The fundamental unit is the point or node, which is stored with a set of coordinates specifying its position. Tables are then constructed with pairs of nodes forming arcs, which in turn are assembled into polygons. Further tables are then constructed linking the points, lines and polygon features with their attributes, i.e. some code or information describing what the feature represents. A feature may have more than one attribute, for instance, an arc representing a road may have attributes describing its status (B-road, A-road, motorway), a number describing its width in metres, and an indicator (called a *flag*) which specifies whether that particular road is prone to congestion at rush hours).

Each dataset can further be thought of as describing one particular topic or theme about the area, and is referred to as a *thematic layer* or a *coverage.*

5.12.5 Digitising and Scanning

The most intensive and time consuming part of a GIS project is usually getting the information into the system in the first place. It may be that the only source of geographic information is in the form of printed maps. To get this information into the GIS it is necessary to convert it into a digital format. Although scanning devices are available which will "rasterise" an image or map, it is still necessary for a human operator to enter the attribute information. Maps scanned in this manner can be used as a backdrop to other data display, but as far as the GIS is concerned, it is just another digital image. Also, information which needs to be in a vector description generally must be entered using a digitising tablet and mouse to trace out features of interest from the map, entering their locations a point at a time into the GIS; this can be a time consuming process. Until computer pattern recognition and processing techniques have progressed somewhat, it will still be dependant on the human operator to interpret printed maps and enter the relevant information into the GIS.

However, in a given project, this stage will only have to be done once. Digital map data is also becoming increasing available, which can readily be incorporated into a GIS.

5.12.6 Sample GIS / Remote Sensing Application

As an example of how a GIS can be used in conjunction with remote sensing data for a particular application, consider the following hypothetical scenario, based on datasets from the Isle of Wight. A number of monitoring stations along a river have detected an elevated level of nitrates in the water, and it is suspected that the source is fertiliser leaching from agricultural land. The task is to delineate the extent of the pollution, and to identify particular fields along the water course which could be responsible.

The following datasets have been assembled:

i) Classified land use image derived from a LANDSAT Thematic Mapper scene.
ii) Locations and measurements of the monitoring stations detecting the pollution.
iii) Vector dataset showing water courses in the area
iv) Digital Elevation Model of the area (raster dataset)
v) Digitised field boundaries and cadastral information

These datasets are shown diagrammatically in Figure 5.12

All the datasets are referenced to a common system (OS National Grid) and input into a GIS. Combining datasets (iii) and (iv) can produce a coverage showing the watersheds and drainage areas for the water courses in the area. Interpolation of the readings and position of the monitoring stations in dataset (ii) can be performed, combined with the drainage information just computed, producing a map of predicted nitrate concentrations in the area. This fulfils the first task.

Figure 5.12 GIS Application IOW Pollution Analysis

The second task can be approached by combining the using the water course vector data from (iii) to produce a *buffer zone* around the water course, showing all areas within 100 m of the river, upstream from the pollution monitoring stations. This is then combined with the land use data to identify areas of agricultural land, currently under crops, which fall into this buffer zone. This information can then be combined with the digitised field boundaries, to identify individual fields which might be the source of the contamination.

Note that this does not give conclusive proof that these fields are the source, but it helps to narrow down possible targets which might then be the subject of a field investigation, allowing manpower and resources to be targeted more effectively.

A further development of this scenario might be to use the GIS modelling capability, to examine the effects of introducing a certain amount of pollutant at different points in the water system, predicting how it might disperse, and which areas of land would be most affected. The effect of changing the water system, perhaps by inserting weirs or dams at certain points could also be investigated.

While this example is somewhat contrived, it serves to illustrate some classic GIS functions and methodology.

5.12.7 Summary

This section has really only scratched the surface of GIS, since it is a whole topic on its own, although it does overlap in several areas with remote sensing studies. GIS can be applied anywhere people need to analyse map related information. The effort necessary to digitise information into the system is usually more than offset by the speed of analysis available with a GIS.

5.13 HARDCOPY OUTPUT

The production of a hard copy enables a permanent record of a processed image or GIS dataset to be made. This can range from a print out from a monochrome or colour laser printer, to photographic negatives or prints. The device which actually does the printing, plotting, etc. is known by the generic name of a hardcopy device. Most hardcopy devices accept digital image files in a variety of standard formats. These formats describe an image, not in terms of remote sensing quantities, but more general print oriented terms, such as dots per inch, and the composition of colours. Some common standard formats are PostScript, Encapsulated PostScript (EPS), Tagged Image File Format (TIFF), and Graphics Interchange Format (GIF). Most image processing packages have a capacity to convert a processed image (for example, a colour composite produced from a geocorrected dataset), into one of these standard formats, to enable it to be printed out. Some hardcopy devices accept package specific formats (such as ERDAS LAN files), but the advantage of the standard formats is that they are generic, and allow easy "portability" of annotated or value added images into word processing, desktop publishing packages or a GIS.

Section No.6

NRA Applications

6.1 INTRODUCTION

As 'Guardians of the Water Environment' the NRA are responsible for every aspect of the management of water resources in England and Wales. Responsibilities include pollution control, management of water extraction and conservation of water environments. The very nature of these duties gives remote sensing a useful role to play.

This section 'NRA Applications', considers the benefits remote sensing can provide to the NRA business sectors. Each business sector is considered, generally to start with, and then by use of case studies which highlight specific applications.

6.2 WATER QUALITY

6.2.1 Introduction

The NRA's aim to 'achieve a continuing overall improvement in the quality of river, estuarine, and coastal waters, through the control of pollution' demands extensive monitoring of U.K. waters. The application of remote sensing techniques has an important role to play and has been addressed by the development of 'The National Centre for Instrumentation and Marine Surveillance ', NRA South Western Region.

The aim 'to ensure that dischargers pay the costs of the consequences of their discharges' also suggests a further application of remote sensing. Evidence of illegal discharges is required to prosecute offenders and plan clear up programmes. Remotely sensed information could be one of the sources of this evidence.

The NRA's water quality strategy states a need to 'investigate the use of novel techniques such as aerial and satellite observation to see how these can be used to identify eutrophic areas, track pollution incidents and provide land-use information for water quality management'. The three case studies which follow highlight the application of remote sensing to the NRA's water quality strategy.

6.2.2 National Coastal Baseline Survey

The Water Resources Act of 1991 requires the NRA to monitor the extent of pollution in controlled waters, out to three nautical miles from the shore. To this end, NCIMS undertakes a regular survey of the entire coast of England and Wales at regular intervals; currently three times a year. This survey combines aircraft remote sensing data with "sea truth" measured from survey vessels and laboratory analyses, producing the most comprehensive archive in existence of information on the quality of the coastal zone. At present, Scotland and Northern Ireland are not surveyed, but it is hoped to include these areas in future surveys.

Survey Methodology

Due to the large area of coastline which must be surveyed in this undertaking, a methodology has been designed to ensure that as complete a picture as possible can be built up of coastal water quality. There are three components to the method:

- **Boat-based sampling:** Water samples and water column profiles are taken from the survey vessel at 186 sites around the coast, at approximately 15 km intervals. These samples are subjected to laboratory analysis for a range of chemical and physical parameters, including suspended solids, chlorophyll related substances, heavy metals and a number of important organic and inorganic compounds.

- **Continuous in situ measurement:** As it sails between sampling sites, the survey vessel takes near continuous measurement of a number of water parameters such as temperature, salinity, chlorophyll-*a* concentration and dissolved oxygen. The parameters are logged with a time and location tags through a QUBIT TRAC V navigation system and GPS.

- **Airborne remote sensing:** In order to get a synoptic view of the whole 3 nautical mile coastal strip, remote sensing data is gathered from an aircraft overflight at the same time as the survey vessels collect the "sea truth". The aircraft carries a suite of sensors, comprising a CASI imaging spectrometer system (see Section 3.1), colour and thermal video, and a still camera. All data acquired by the sensors are logged with time and position from a GPS.

The remote sensing data can the be calibrated from the sea truth measurement to provide a variety of descriptive information about the coastal zone. The results of the survey can be used for different applications such as mapping of different water bodies, mixing zones from rivers and outfalls, and suspended sediment / chlorophyll distribution.

For examples of typical CASI images and applications, see Plates in Section 3.1.2.

References

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6.2.3 Assessing Likely Sources of Agricultural Pollution

Introduction

Of all farm pollution incidents 87% are due to organic wastes, oil represents 3%, pesticides 2%, nutrients less than 1% and all others 7% (NRA, 1992). The E.C. Drinking Water Directive (80/778/EEC) sets maximum admissible concentrations for various substances in drinking water supplies. The control of pesticides and nitrates is of particular relevance to agriculture. Pesticide levels can also be controlled through the Food and Environmental Protection Act 1985. The NRA can impose further controls should they wish, by tighter restrictions on pesticide use in water protection zones.

NRA South Western Region - Maize Identification Project

The South Western Region of the NRA, South Wessex Area has a predominantly agricultural land use which could consequently lead to a risk of contamination of controlled waters due to pesticide use. Recent analysis of samples has shown that, on occasions, the herbicide Atrazine is present in excess in some watercourses and ground waters and has led to breaches of the limits set down in the EC Drinking Water Directive. Investigations have also shown that an increase in the use of land for maize crops may be a source of the Atrazine contamination.

The NRA is addressing this problem by using satellite imagery to investigate the location of land areas used for maize crop production and will use this information to target pollution control activities. The ultimate aim being to reduce Atrazine contamination. The project involves the six sub catchments of the River Avon and the study will identify which parts of which catchments are vulnerable to Atrazine contamination. This will allow the targeting of investigations by analysis of water samples and farm visits. This targeting will lead to manpower and analysis cost savings (NRA, 1995).

The NRA also wishes to identify change in the area of land used for maize crops between 1989 and 1995. Using satellite imagery estimations of the area of land and the percentage of land used for maize in each sub catchment can be calculated for each of the specified years.

Methodology

From the available data sources, SPOT multispectral or Landsat Thematic Mapper data would be the best to apply to this project. The use of both these data has been proven suitable for crop identification purposes. The methodology to use would be a supervised classification. Figure 6.1 shows a SPOT multispectral image with field boundaries digitised and the different crops identified. The imagery needs to be selected to coincide with the

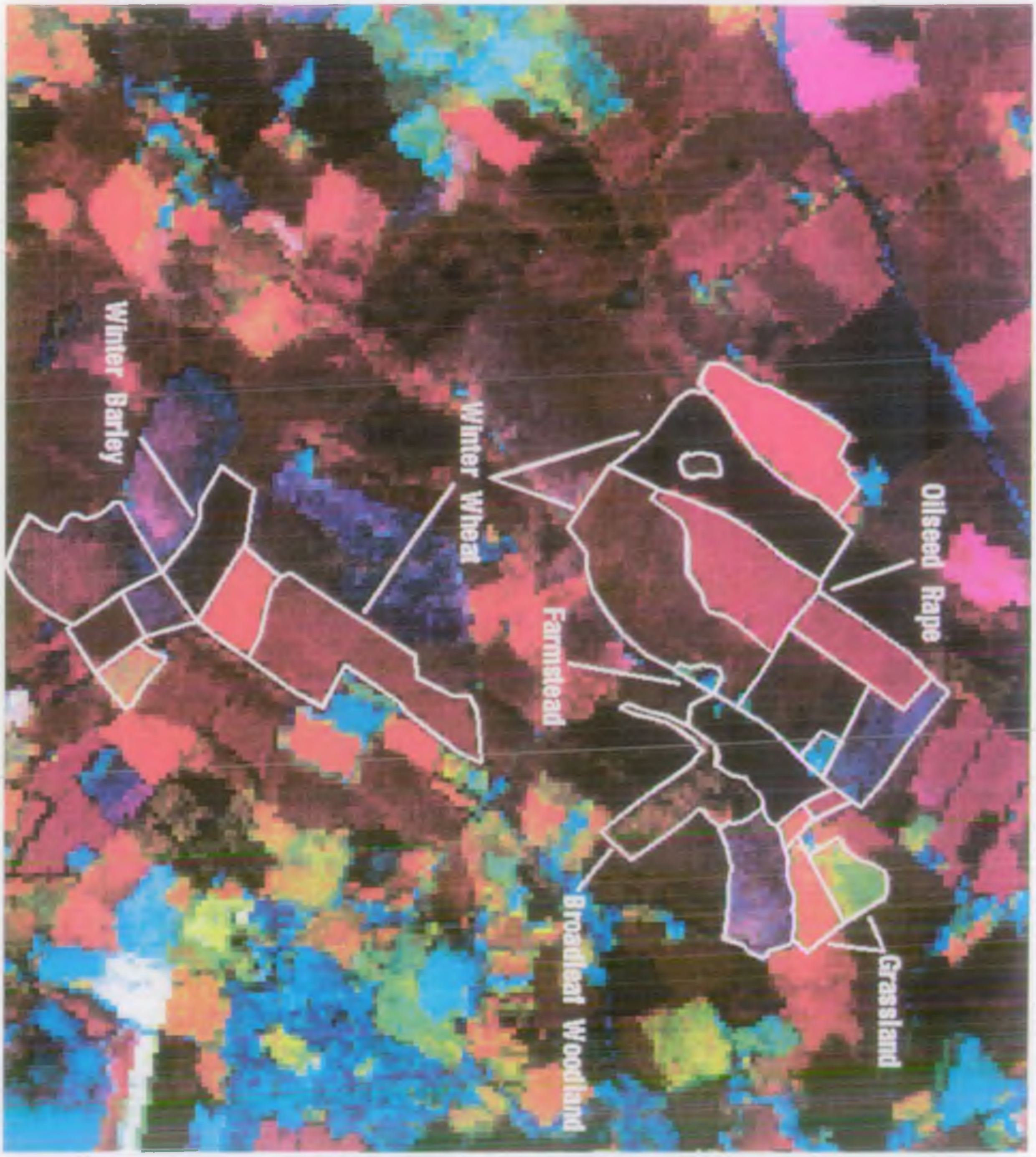

Figure 6.1 SPOT XS Classificaiton of Crop Types

maize growing season and lack of cloud cover is important to a project such as this. Pre-processing requirements include atmospheric correction, contrast enhancement and geocorrection of the imagery. The next step is to undertake a classification of land use.

To undertake a supervised classification ground truth information is required. Details of known maize production fields, can then be used to train the classification. The majority of known maize production areas can be used to train the classification algorithm and the rest used as verification of the result. Using the training data, individual spectral signatures can be extracted from those fields in all image bands. Creating class signatures also involves the calculation of associated statistics (standard deviations, means, minimum and maximum values). Distance and divergence measurements can also be evaluated to determine the class homogeneity.

Once a set of reliable signatures had been created and evaluated, the next step is to perform a classification of the image. Each pixel in the image will have an associated measurement vector which is compared to each signature, according to a decision rule or algorithm. Pixels that pass the criteria established by the decision rule are then assigned to the class. The maximum likelihood decision rule is often used, this is based on the probability that a pixel belongs to a particular class.

Once the classification process is complete a raster image with two classes, maize and non-maize areas is produced. The best method for dealing with this is to vectorise the information, i.e. make it into a line map. An automatic process can be used to achieve this either in the image processing system or in a Geographic Information System (GIS). Once the information is vectorised it can be extracted using the sub-catchment boundaries. This would give the six sub catchments of the Avon as separate digital maps showing maize production areas. The total area of maize in each of the sub-catchments can then be automatically calculated as can the percentages of maize out of total land areas.

A number of other functions can be applied to the data depending on requirements. For example details of the local river system can be digitised either from the image or an Ordnance Survey map. Combining this information with the maize production areas allows spatial analysis. A Geographic Information System can be used to identify all maize fields within say 50 or 100 metres of a watercourse. Combine this information with ground water features such as faults and joints and an advanced application solution begins to take shape. The information required can then be produced in statistical form or paper maps to take into the field. Production of the maize maps on acetate sheets would enable their overlay on to Ordnance Survey maps used in the field thus producing maximum levels of information.

References

NRA, 1992, *The influence of Agriculture on the Quality of Natural Waters in England and Wales.* Water Quality Series No. 6.

NRA,1993, *Water Quality Strategy.*

NRA, 1994, *South Wessex Maize Identification Project,* Invitation to Tender Technical Requirements.

NRSC 1992, *Evaluation of Remote Sensing to Determine Catchment Parametres fort he Kennet Drainage System.*

6.2.4 Thermal Pollution Monitoring

There are many sources of pollution that can be detected by a thermal signature, not least power station outfalls. Power stations generally require large amounts of cooling water and consequently are situated on the coast or by large lakes or rivers. It is often hard to separate the effects of hot water from other features of discharge. Associated problems are the discharge of chlorine to discourage the settlement of organisms in the heat-exchange system, scour of the bed and leaching of metals. There are two distinct phases in the dispersal of the warm discharge water. First a thermally stratified plume forms extending down current from the outfall. The temperature decreases as it mixes with the surrounding waters until it is vertically well mixed. The rate of mixing is determined by the local currents and meteorological conditions. The plume is then cooled by further mixing with surrounding water and loss of heat into the atmosphere.

Sensors working in the thermal infra-red portion of the electromagnetic spectrum are available both on satellite and airborne platforms depending on the resolution required. These sensors can not only detect thermal pollution but other pollution sources which give out a thermal signature. Of the spaceborne sensors NOAA AVHRR, ERS-1 ATSR and Landsat Thematic Mapper's thermal band can be used for thermal monitoring. AVHRR and ATSR have a one kilometre resolution so are suitable for regional monitoring for example of coastal regions. Landsat Thematic Mapper Band 6 has a spatial resolution of 120 metres so can be used for monitoring more localised areas.

The waters in the vicinity in Llyn Trawsfynydd Power Station cooling water outfall, North Wales, were investigated in the 1980's to assess the methodology for detecting thermal plumes. Figure 6.2 shows the lake, the power station is located on the north eastern corner of the lake shore and produces a large volume of cooling water which sets up strong thermal gradients which can be seen on the imagery. The colours displayed show approximately 1° Centigrade differences. To produce these temperature classes an image processing technique known as density slicing is applied. The colours are applied by classes of digital number which describe relative water temperatures. Once density slicing has been applied the class boundaries can be vectorised to produce a line map if required.

Landsat Thematic Mapper imagery can be used to give relative temperature changes, but without 'ground truth' absolute values of temperature are not possible. If absolute temperatures are required sample data taken at the time of imaging is required to correlate the digital numbers in the imagery. Comparison of different dates also requires ground truth and the changing atmospheric effects on the imagery must be considered. Figure 6.3 shows the changes in the thermal structure of the plumes in the lake on four different dates. The influence of wind direction on surface circulation is clearly visible. On the 16th October 1986 the wind was from the south west until 09.30 hrs and then changed rapidly to due west by

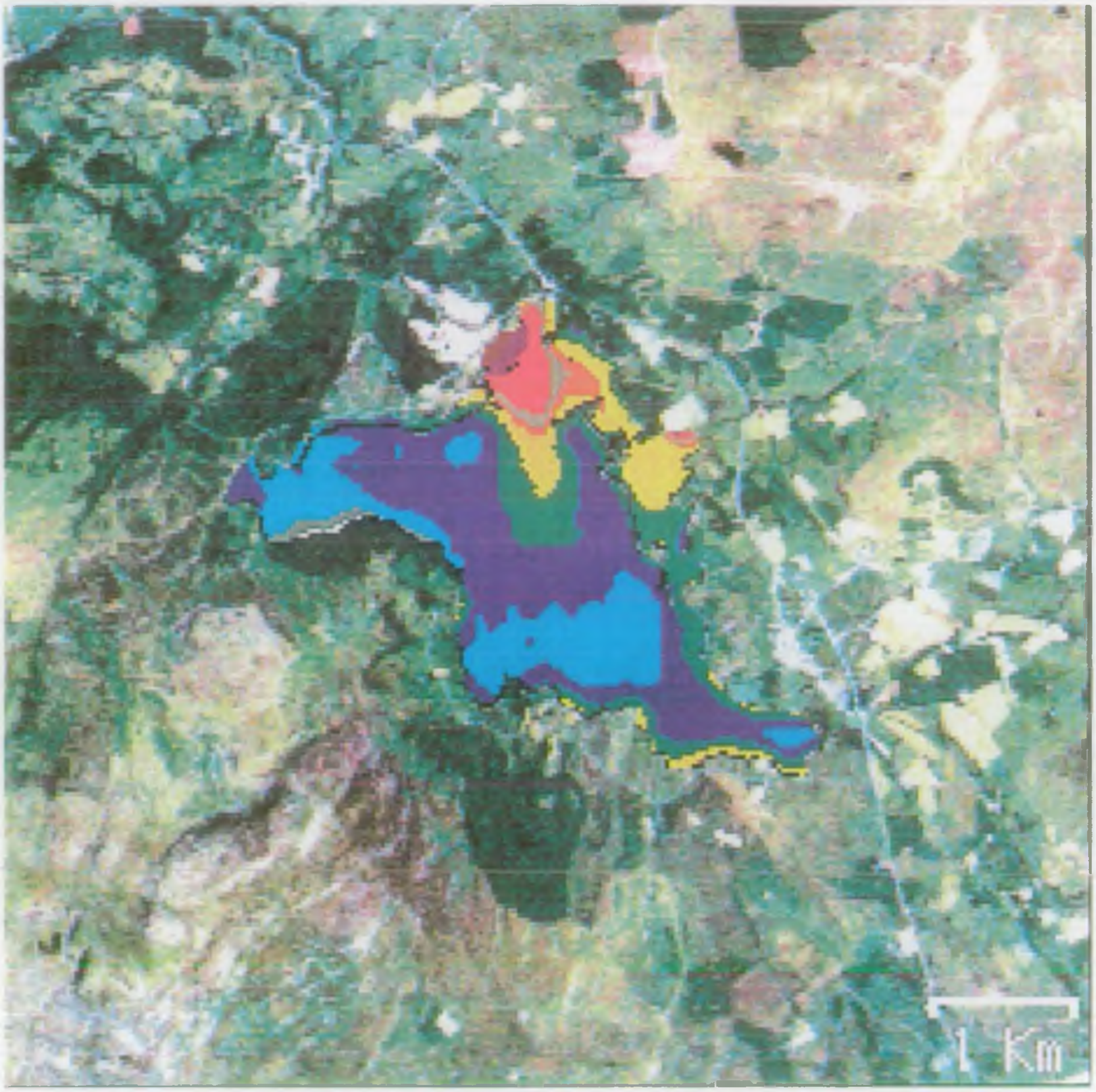

Figure 6.2 Relative Temperatures in Llyn Trawsfnyyd , North Wales

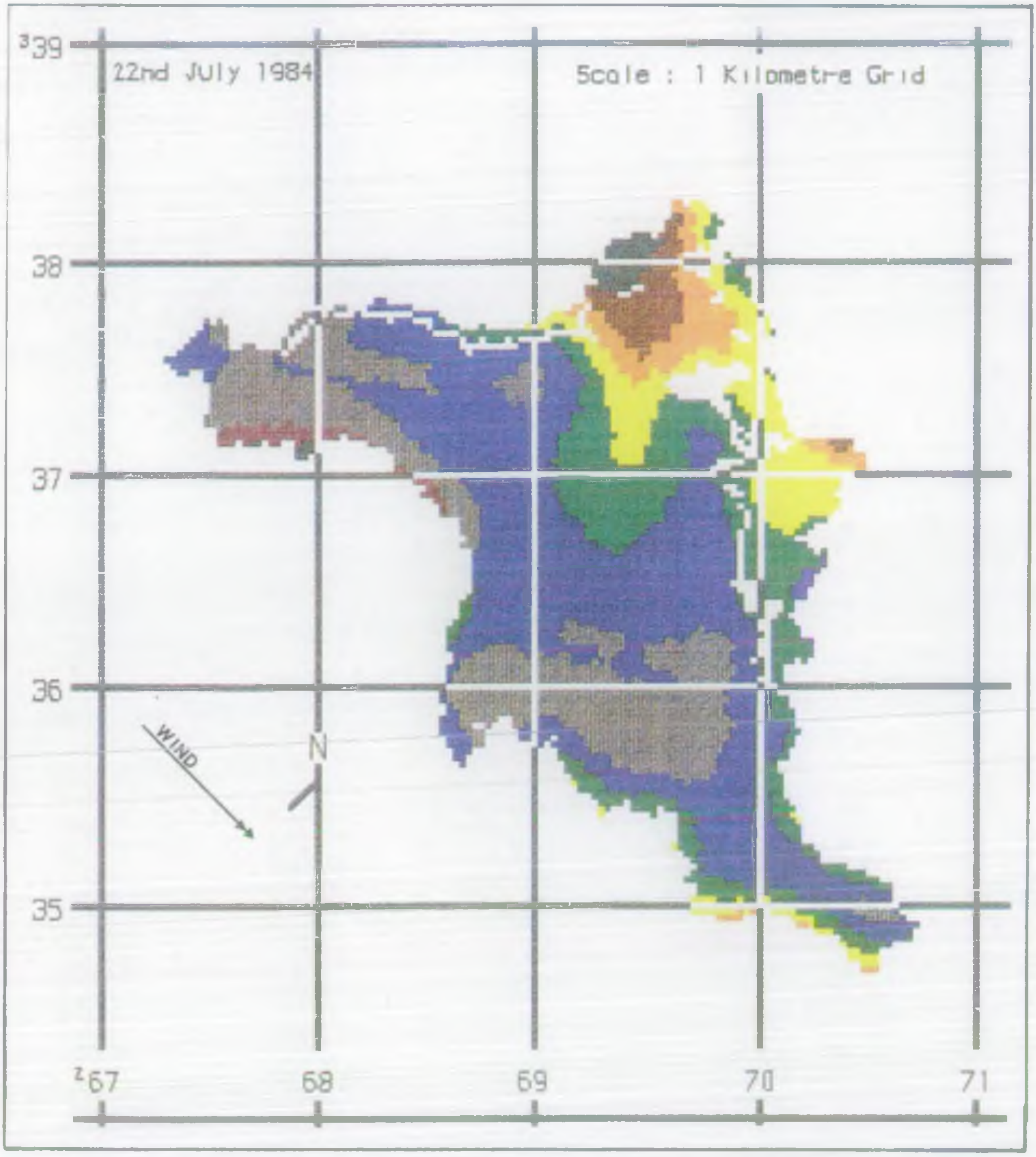

Figure 6.3a Temperature Patterns in Llyn Trawsfnyyd

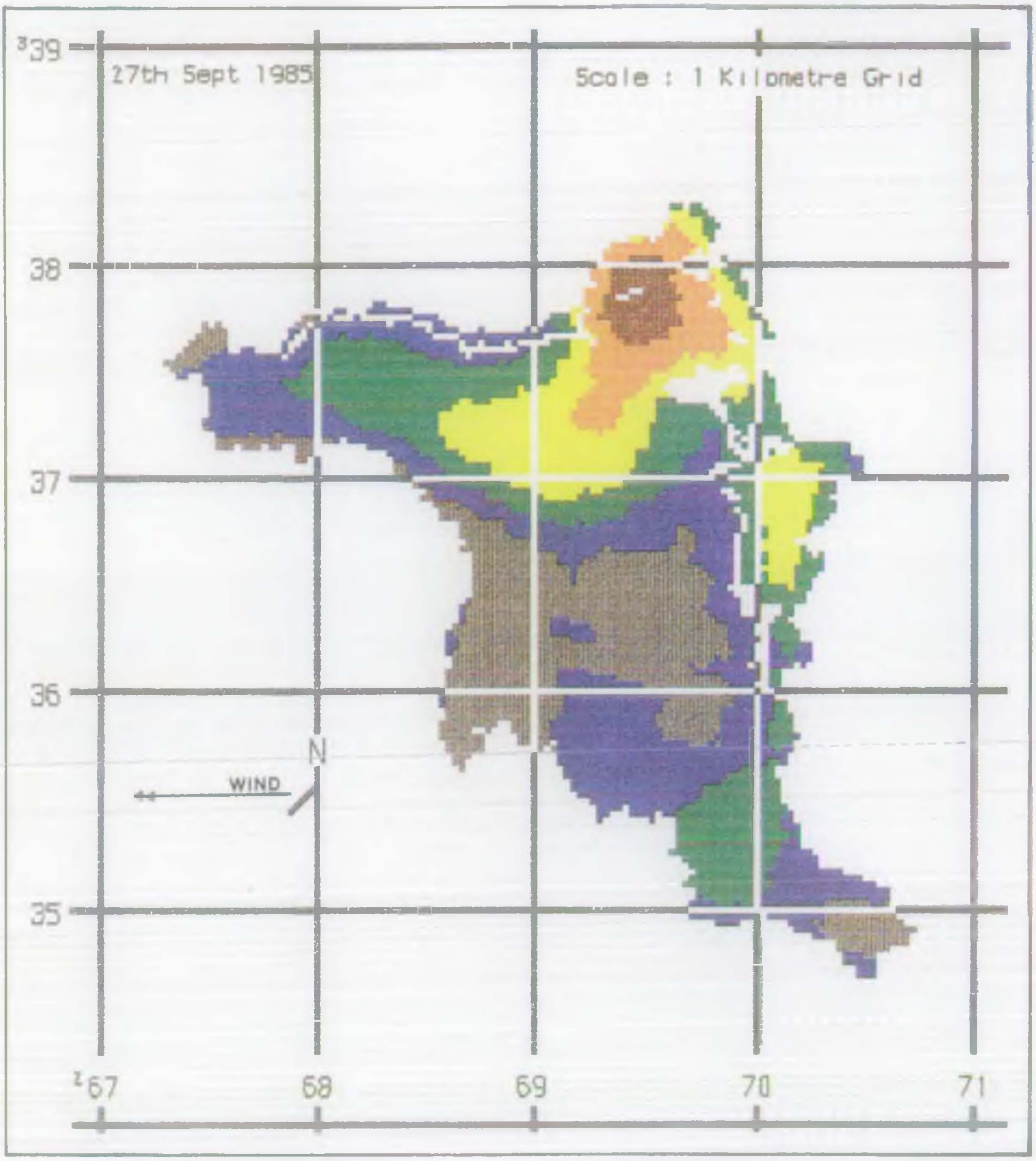

Figure 6.3b Temperature Patterns in Llyn Trawsfnyyd

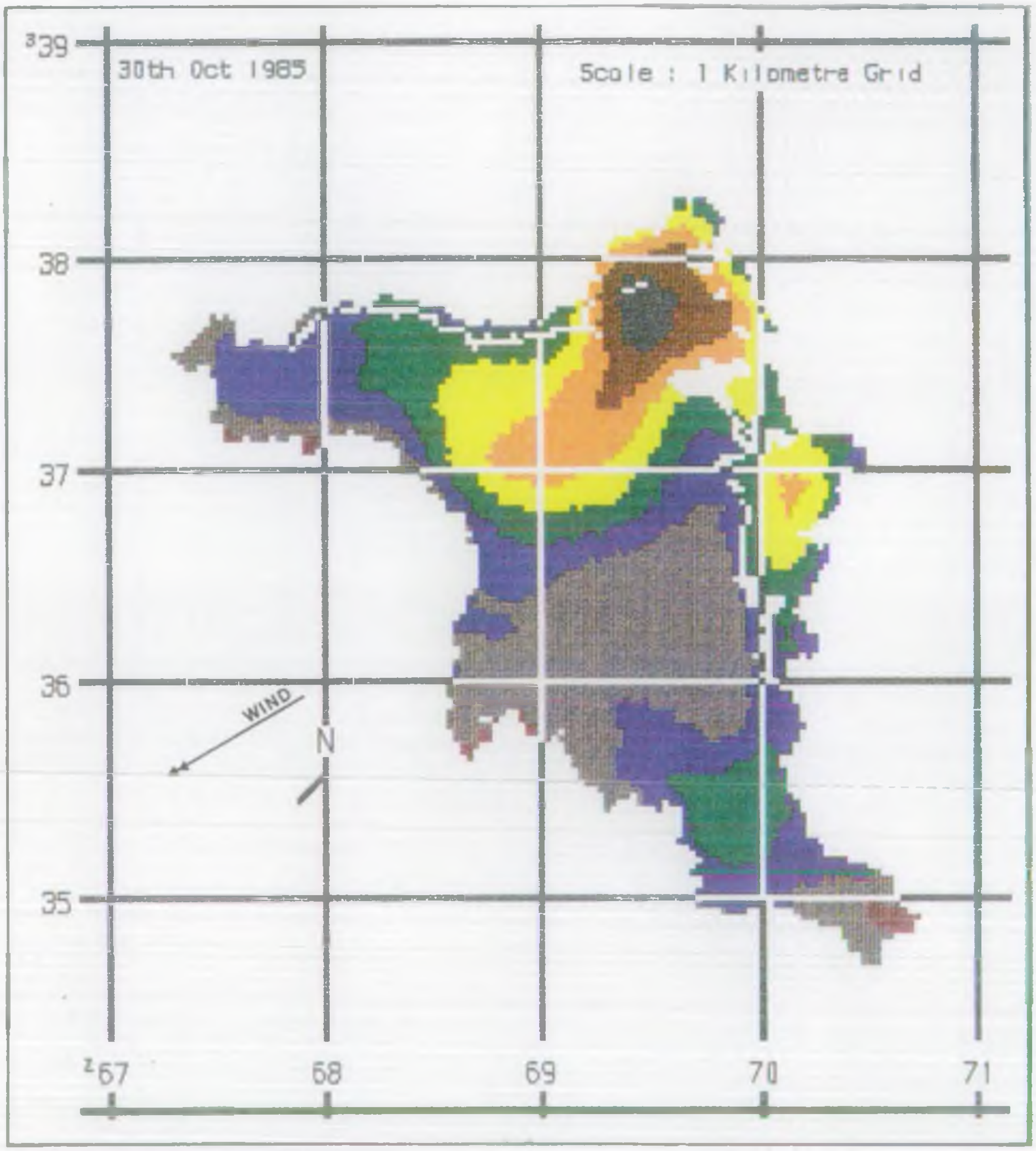

Figure 6.3c Temperature Patterns in Llyn Trawsfnyyd

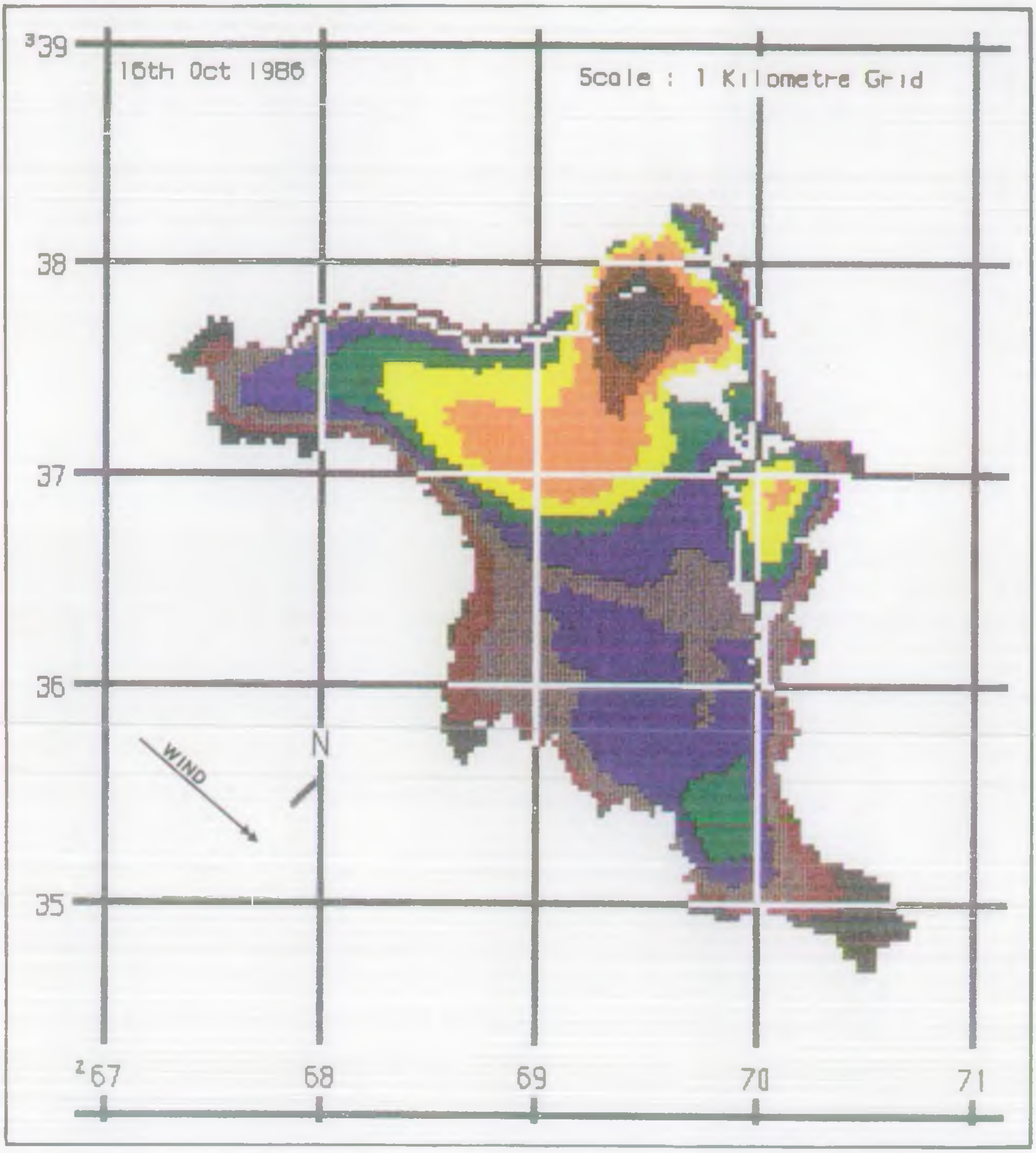

Figure 6.3d Temperature Patterns in Llyn Trawsfnyyd

12.00 hrs. The warm water near the outfall at the time of the overpass, 11.00 hrs, can be seen beginning to swing round to spread eastwards as it follows the new wind direction.

For larger scale studies airborne platforms can carry thermal scanners such as the Talytherm infra-red imaging system, already used by the NRA. The Airborne Thematic Mapper sensor also has a thermal infra-red band which is useful in combination with its other visible and infra-red bands. One drawback of the CASI system is the lack of a thermal channel. In comprehensive monitoring programmes especially of coastal waters thermal data complement visible data and in some cases can offer a new perspective.

References

NRSC, *Mapping Outfall of Power Station Waters - Llyn Trawsfynydd,* Information Leaflet.

Southampton University, Department of Oceanography, 1993, *Airborne Remote Sensing of Coastal Waters*, NRA R& D Report 4.

6.3 WATER RESOURCES

6.3.1 Introduction

One of the NRA's aims is to 'manage water resources to achieve the right balance between the needs of the environment and those of the abstractors'. To achieve this aim catchment management plans which address all the NRA's functions within a river catchment are drawn up. Additionally in areas where water levels are managed, MAFF's 'Conservation Guidelines for Drainage Authorities', 1991, states that Water Level Management Plans should be produced. Both of these are working documents which are updated or revised when circumstances change. Remotely sensed information can be both useful for identifying and monitoring water resources and has a role to play in the management of these resources. The following examples discuss the use of remote sensing firstly for analysis and identification of pollution risk zones and secondly as an information source for water level management plans.

6.3.2 Hydrogeology

Remotely sensed imagery can be used to investigate fractures, faults or joints, which serve as channels for the movement of water. This information is necessary both for water extraction purposes and in determining high-risk zones of pollution. On satellite imagery fractures show as linear features which may find topographic expression, expression by tonal contrast in soil covered areas or linear change in vegetation pattern. These forms of expression may in turn be due to one or more changes in underlying rock type, change in soil or change in soil moisture.

Selection of lineaments of hydrogeological significance depends on their geological setting and therefore imagery is used in conjunction with geological mapping. Landsat Thematic Mapper imagery, Spot stereopairs and Synthetic Aperture Radar are all useful for this application. Thematic Mapper can be used to produce colour composite images which are generated using intensity-hue-saturation transforms. A digitised geological map can be used to control the hue while the intensity is controlled by a single-band, image filtered to enhance lineaments. The saturation is controlled by surface elevation. Different types of imagery may not necessarily reveal the same lineaments and detailed interpretation is required.

SPOT stereopairs can be used to interpret regional faults and minor local fracturing at scales of between 1:100,000 and 1:50,000. Once this is achieved statistical processing of the interpretation including direction filtering, directional histograms, fracture density mapping and field work will allow channels to be identified. A typical flow diagram of stages in a programme and the place of imagery in such a programme is shown in Figure 6.4.

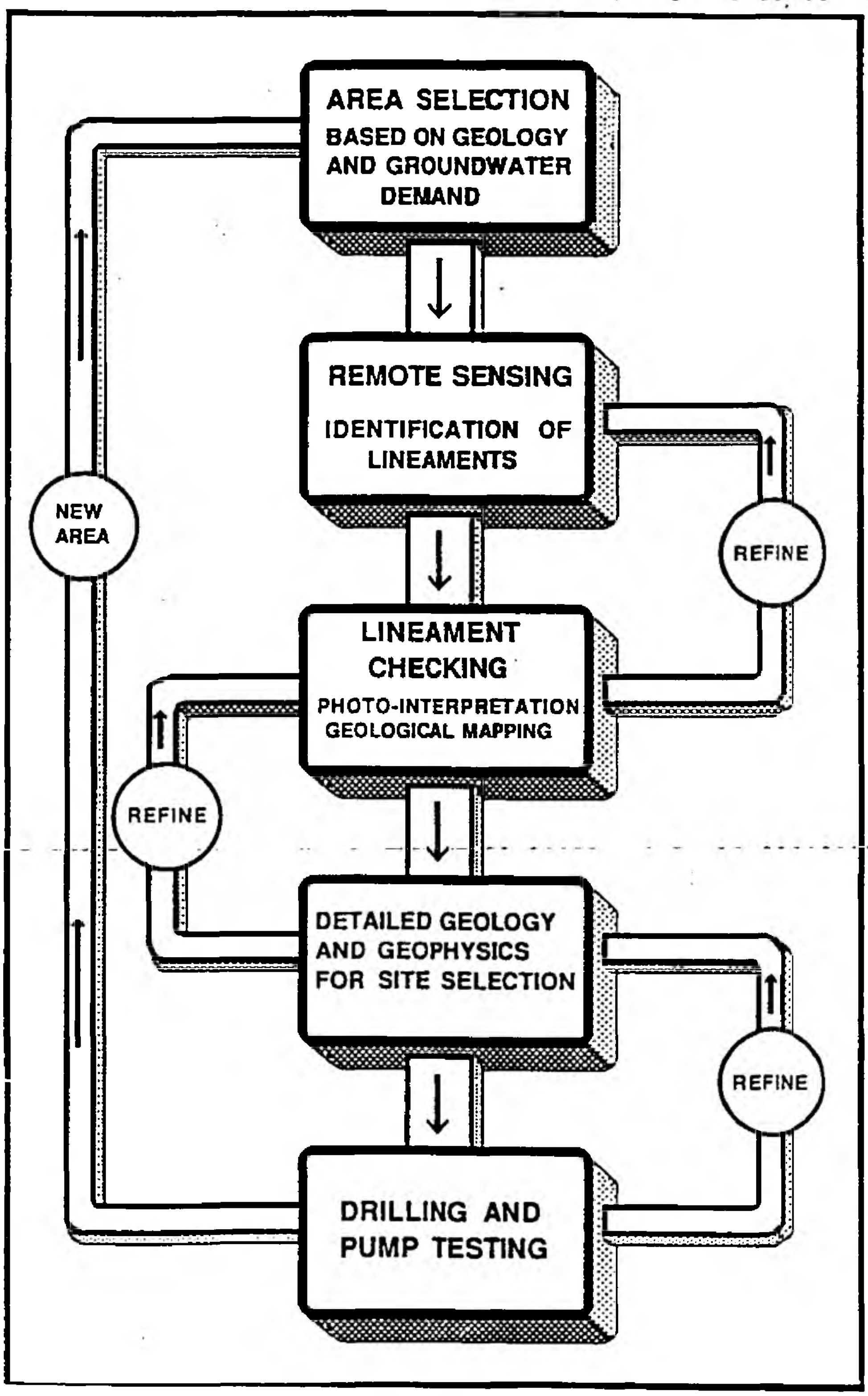

Figure 6.4 A Ground water programme using Remotely Sensed Data

6.3.3 Water Level Management Plans

Water level management plans are developed to provide a means by which the water level requirements for a range of activities in a particular area, including agriculture, flood defence and conservation, can be balanced and integrated. These water level management plans whilst not being statutory should be incorporated into other strategies and plans and in particular they should be treated as the central component of an operational plan for the area. (MAFF, 1994) Hence, water level management plans are an essential input into Catchment Management Plans and may be useful for coastal authorities when preparing Coastal and Shoreline Management Plans.

MAFF recommended that plans be prepared for all areas which have a conservation interest and where the control of water levels is important to the maintenance or rehabilitation of that interest. These wetlands, often being Sites of Special Scientific Interest (SSSI's), are particularly important for archaeological remains which may require special management. In preparing a plan the first recommendation is that the area covered is to be defined. Remote Sensing has a role to play here. A map showing the site boundary, watercourses, water management structures, normal flow directions and designated conservation areas is required. Use of a recent SPOT or Landsat Thematic Mapper scene will afford production of an up to date map for such purposes. The ability to produce classifications of lowland peat, agriculture, forestry, commercial, flood defence, roads and recreational areas allows the authority to begin considering the potential conflicts of use within an area, prior to consultation.

Figure 6.5 shows a Landsat Thematic Mapper scene automatically classified, showing peat in purple and woodland as dark green. Previously unmapped areas of lowland peat were identified prior to an aerial photography and ground survey programme. The use of satellite imagery and aerial photography to monitor change in water level management plan areas should also be useful.

MAFF's guidelines on Water Level Management planning note that 'while there may not be comprehensive data on all aspects of a site, plans should be prepared on the basis of the best information available'. Remotely sensed information can be of great benefit in this respect by giving an overview of the area or more detailed information using aerial photography, whilst keeping ground survey costs to a minimum.

References

MAFF, 1994, *Water Level Management Plans - A Procedural Guide for Operating Authorities*

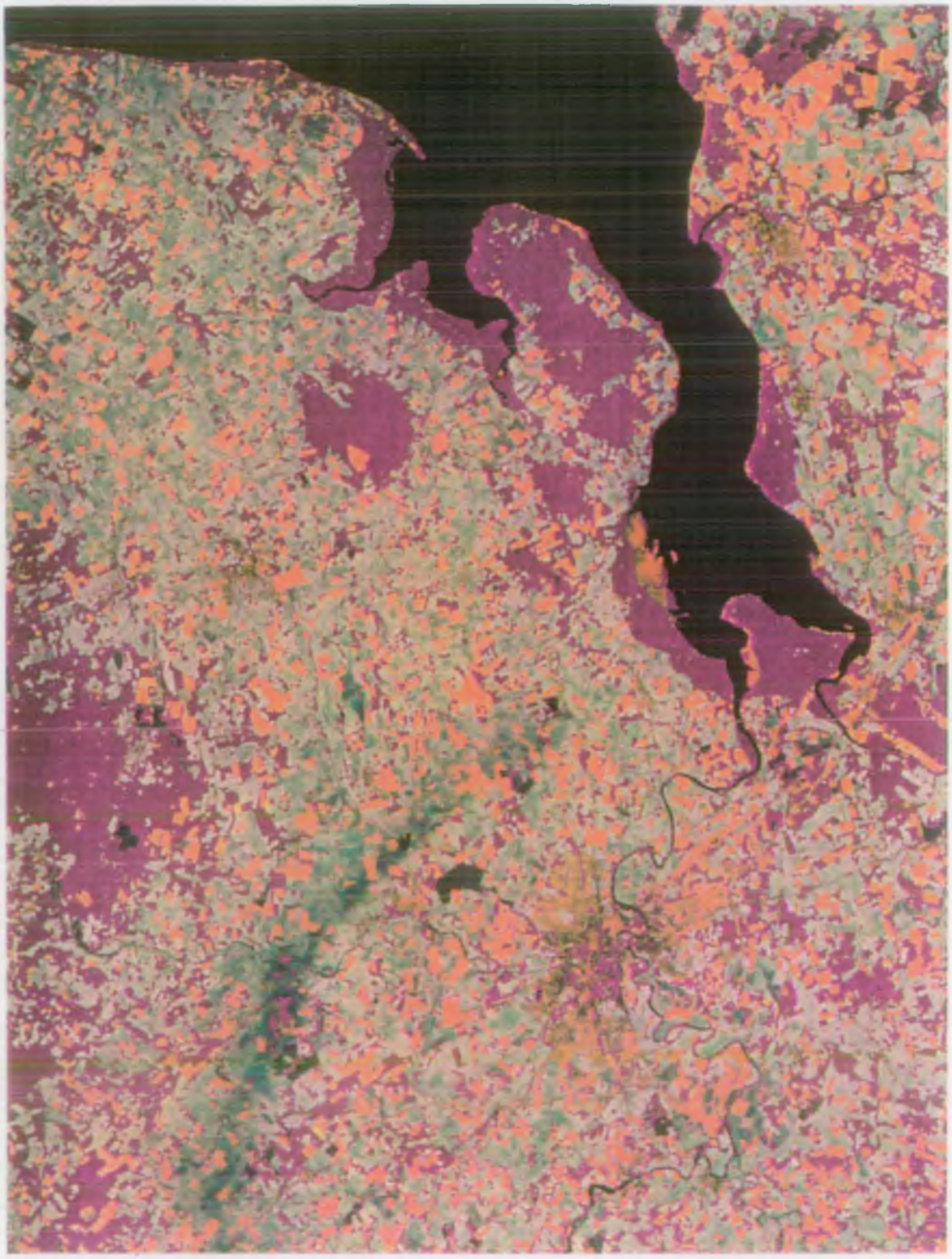

Figure 6.5 Lowland Peat Classification using Landsat TM Data

6.4 FLOOD DEFENCE

6.4.1 Introduction

As part of their remit the NRA aim to provide effective defence for people and property against flooding from rivers and the sea and provide adequate arrangement for flood forecasting and warning. The emphasis here is on knowledge of natural systems, how man has affected them and the consequences which can arise because of this. Again remotely sensed information has a role to play in this knowledge gathering process. Only by building up a comprehensive database of time sequence information can the effects of natural processes be understood.

The following sections consider the use of aerial photography for mapping and monitoring coastal change. NRA has a full archive of aerial photography for the South Coast since 1991. The use of Synthetic Aperture Radar imagery to help in flood analysis studies is also considered.

6.4.2 Coastal Mapping

Recent developments in aerial photography now mean that photographs can be scanned into image-processing systems and treated in the same manner as satellite imagery. This allows far greater flexibility and the processing ability to consider change detection between dates. Using stereo-pairs of digital photographs digital elevation models of topography can be produced to high levels of accuracy (+/- 5 cm). This will significantly assist flood defence studies and monitoring projects in the future.

With the continued move towards soft sea defences and managed retreat there is a greater need for repeat monitoring of coastline. The development of shoreline management plans is a significant move to address this issue. Regular monitoring can be achieved using aerial photography to keep ground survey costs to a minimum and the information obtained from an airborne survey often gives a better overview of coastal change. The coastal zone is subject to great change within very short timescales but the effect of winter storms is often counterbalanced by summer beach building processes. Repeat surveys of the coastal zone would allow changes in beach profiles, vegetation cover and man's activities to be monitored.

The use of aerial photography for coastal monitoring is becoming more frequent, specifications often ask for a scale of 1:3,000 in order to achieve a height accuracy of +/- 0.05 metres. Depending on requirements new photography can be flown or data can be obtained from the NRSC archive or other local archives.

For beach profiles low tide photography is required extending from the water level to stable ground, for instance a tarmac road. The aerial photography is controlled using detail points and spot heights from OS 1:1250 and 1:2500 base mapping and can be supplemented with additional ground survey photo points. Profile data can be captured by traditional photogrammetric methods using analogue and analytical stereo plotters. Alternatively digital methods can now be used. The profiles can be selected to follow exactly previous surveys and 3D diagrams of the shoreline can be produced. Points of change in slope are digitised for export into GIS and AutoCAD.

Figure 6.6 is a 1:25,000 (reduced) aerial photograph of Brean Down and the Severn Estuary. Figure 6.7 is a large scale photograph of inland flooding, discussed in the next section.

Figure 6.6 Brean Down and the Severn Estuary

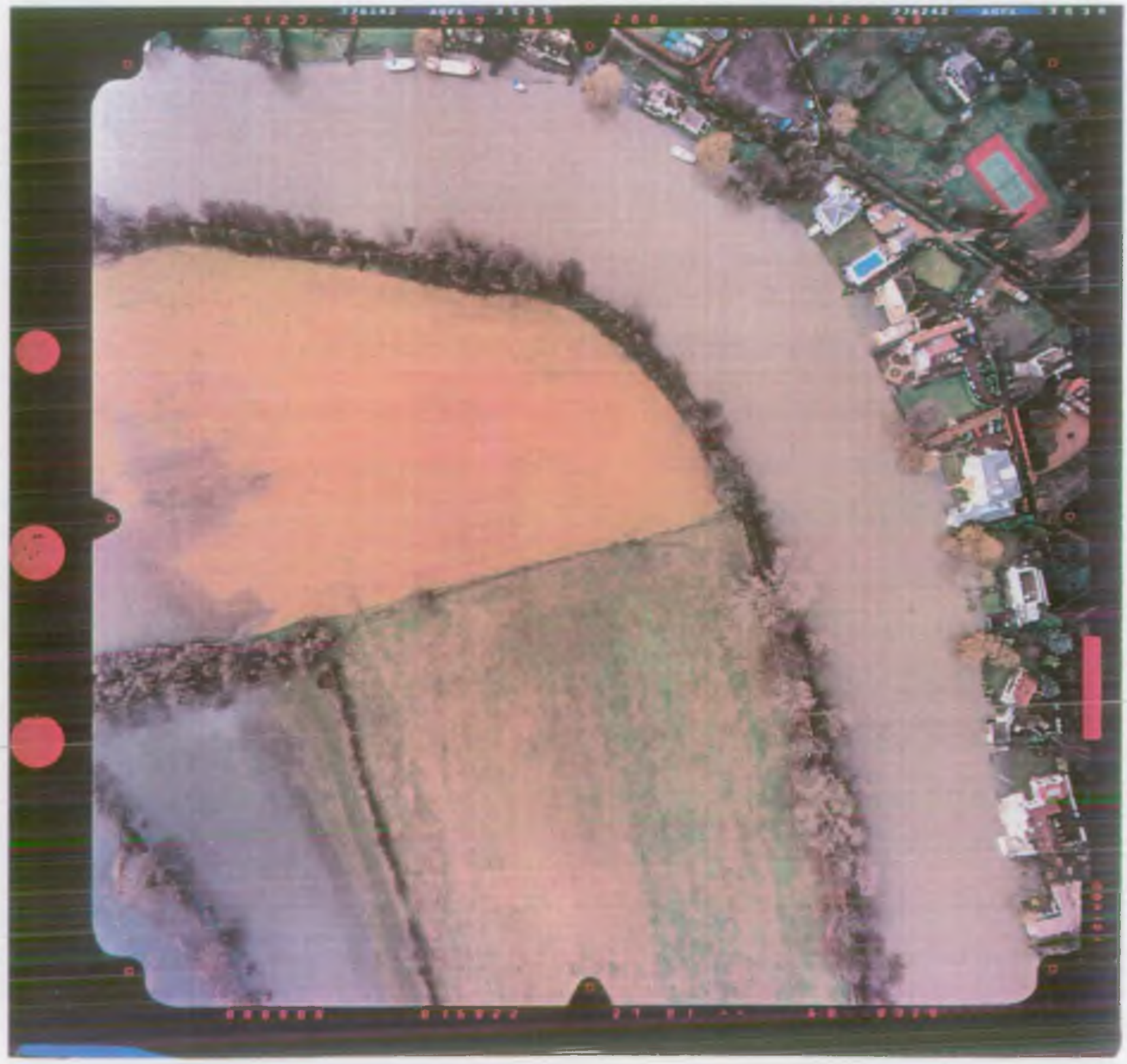

Figure 6.7 Large Scale Aerial Photography of Flooding

6.4.3 Flood Analysis

The same procedure is also applicable to inland flood defence problems. For example the need to ascertain flood plain levels relative to water levels and flood defence works. Analysis of changing river channel morphology and run-off characteristics are a couple of further examples.

However the combined effects of soil moisture and flooding mean that inundation is rather more unpredictable, so real time monitoring of extreme events is useful. The cloud penetrating capability of ERS-1 Synthetic Aperture Radar allows provision of a unique temporal data set for the observation of hydrologically significant changes on the land surface. Near real time data is also a feature of ERS-1 SAR allowing analysis and action within hours. The repeat frequency of SAR is 35 days which is not regular enough for flood monitoring. However, when RADARSAT is launched in September 1995, the combined coverage of the two satellites will enable the UK to be observed every three days. The ability to fly airborne surveys during flood periods is often hampered by cloud and poor light. This is not a restriction with satellite radar data, and a whole river system can be analysed effectively.

A still water body will normally appear black in a radar image due to the minimum radar echo and thus flood areas can be defined. However large area water bodies may present various reflectances depending on wind wave characteristics making delineation harder. Other features such as tarmac roads and airports will give low signal returns but should be distinguishable from flood inundated areas by their form. Figure 6.8 shows SAR imagery used for flooding analysis.

Figure 6.8 shows the River Rhine at Cologne in three SAR images of different dates. Areas of white, black or grey show areas of no change, while areas of strong colour indicate significant change due to snow or flooding. Figure 6.9 shows two SAR scenes of a lake, and a combination of the two scenes, highlighting change in the lake condition between the two dates.

With the higher repeat frequency in September 1995 flood stage measurements should be possible. By use of a digital elevation model, a land use map (SPOT/TM scene), and a sequence of SAR scenes of a flood event water levels can be determined and the types of land affected determined. From the SAR scene the extent of flooding can be determined. The boundary can be vectorised and overlaid onto a land use map to highlight land use types affected. By taking the flood boundaries and imposing them on a digital elevation model an estimation of flood water stage height can be determined over time. Such information is invaluable for planning flood defence works.

Figure 6.8 Three Synthetic Aperture Radar Images Overlaid to show Flood Extent (see section 6.4.3 for information).

Figure 6.9 Two Synthetic Aperture Radar Images Showing Lake Fluctuations (top and middle) and the Images Combined (bottom) to Show the Difference in Lake Extent.

Still with regard to flood defence management, NRSC has recently completed a Land Value Classification for the National Rivers Authority, Anglian Region. The classes interpreted included urban, agricultural, recreational, and commercial which can be ranked in terms of value and the need to protect them from flooding. This is essential to prioritise work programmes and complete environmental impact and cost benefit analysis programmes.

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6.5 RECREATION AND CONSERVATION

6.5.1 Introduction

The NRA's aim 'to develop the amenity and recreational potential of inland and coastal waters and associated lands and conserve and enhance wildlife, landscape, and archaeological features associated with inland and coastal waters of England and Wales' is very broad and wide reaching. As we have seen earlier the conservation of archaeological features, so well conserved in lowland peat and wetland areas, is being dealt with by Water Level Management Planning. Catchment Management Plans provide a comprehensive framework for addressing all the NRA's functions within a river catchment including the recreational and conservation aspects.

The first case study considers work which is being done in Langstone and Chichester Harbours which are under investigation as possible eutrophication problem areas. The second considers River Corridor Assessment using aerial photography.

6.5.2 Vegetation Mapping

Coastal and intertidal vegetation mapping and monitoring, to investigate the presence of eutrophication and also to study the effects of sea level rise on saltmarsh vegetation, is an application suitable both to satellite imagery and aerial photography. Landsat Thematic Mapper has suitable wavebands to characterise saltmarsh communities and infra-red false colour aerial photography, originally developed for camouflage detection during the Second World War, is useful at larger scales.

The Thematic Mapper spectral bands most suitable to this study are TM2 (green) because of its high transmittance through shallow water and strong reflectance by healthy vegetation; TM3 (red) because of its high reflectance from non-vegetated surfaces and strong absorption by water; TM4 (near infra-red) because of its very high reflectance form vegetated surfaces and very strong absorption by water; and TM5 (near infra-red) because it allows subtle variations in absorption by water to be detected while retaining high reflectance from vegetated surfaces. These data have been used successfully in the past to determine, upper marsh mixed communities, middle marsh communities, mud and sandflats and coarser sands associated with marsh erosion. Ideally supervised classification methodologies are required with training and verification data, collected at the same time as image acquisition.

Using the higher resolution of infra-red false colour aerial photography means analysis at scales of up to 1:10,000 is possible. Chichester and Langstone Harbours show eutrophic symptoms exhibited by growth of the green macro-algae *Enteromorpha* and *Ulva.* The intertidal vegetation of these harbours have been extensively mapped between 1979-1981 and now the NRA are carrying out further studies for change detection purposes, using CASI data.

IRFC is a tri-emulsion film, its layers being sensitive to green, red, and near infra-red radiance levels. A yellow filter is always placed over the lens to absorb blue light to which the layers are also sensitive. When IRFC film is correctly processed the resulting colours will be false for most natural features. Dominant green reflectance reproduces as blue; dominant red reflectance reproduces as green and dominant near infra-red reproduces as red.

Healthy vegetation will appear magenta or red hues on infra-red colour film because of the high near infra-red reflectance from the mesophyllic tissue of the leaves. This film can also be used to detect losses of plant vigour, when vegetation becomes stressed some collapse of the intercellular spaces within the mesophyll tissue will take place, the infra-red reflectance drops and this is reflected by changes in the film colour.

Infra-red false colour imagery (IRFC) is particularly useful for saltmarsh vegetation mapping because of the large contrast between water, sediments and vegetation species. Previously measurements of the total and percentage area coverage of the following species groups were possible in Langstone and Chichester Harbours and the same classes are envisaged for the current NRA study; *Enteromorpha, Ulva lactuca, Fucus, Zostera, Spartina*, mixed groups, other species and bare substrate.

IRFC is an established operational methodology for performing this kind of study. However, the same analysis can be undertaken more efficiently using digital scanners (particularly imaging spectrometers such as CASI), with automated digital image processing and classification techniques.

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6.5.3 River Corridor Assessment

A standard methodology for conservation surveying of river corridors was decided upon by the NRA in 1992. The need for rapid cost-effective assessment of the conservation features and enhancement potential of river catchments, which complements the detailed ground surveys of river corridors was realised. The conclusion reached was that aerial photography could feasibly provide this overview necessary for both strategic planning purposes and operational use. Its use was identified as particularly suitable for identifying enhancement opportunities in the flood plain and acting as a rapid assessment mechanism for conservation staff when considering planning and other applications.

Small scale photography at 1:25,000 scale can be used to map entire river catchments. Important aspects to consider when viewing the river catchment include urban extent and the presence of woodland. By using a time series of photographs (say once every ten years), urban and woodland change can be monitored. Both of these have a great bearing on in stream conditions through their effects on runoff. Deforestation and urban growth both increase runoff through a reduction in transpiration and infiltration, which can cause serious changes to in-stream conditions and the stability of the river corridor itself. Catchment scale agricultural practices can also be studied using airphoto interpretation with reference to their side effects on the river corridor. One example of this is the mapping of ploughed land (especially on steep slopes) around a river, which can cause serious in-stream problems arising from sedimentation.

The use of 1:25,000 photography enables the immediate surroundings of a river to be studied, including both the corridor and the flood plain. Habitat features including woodlands, unimproved grasslands and wetlands can be mapped in detail. Assessment of habitat quality can be achieved and actions taken from the results. Flood risk can also be mapped from the air, using photo interpretation techniques. Low lying areas adjacent to rivers can be seen clearly using stereoscopic viewing, whilst flood alleviation schemes including channelisation, the creation of berms (two-tier channels to increase capacity) and flood banks can also be mapped. Most importantly perhaps, air photo interpretation can be used to detect previously unmonitored changes in such structures. River bank quality and stability can also be assessed using photo-interpretation. The presence of a riverbank or vegetation can be seen, as well as areas of high erosion, which can be the result of catchment wide or in-stream practices.

Finally, the interpretation of large scale photography can be used to study in-stream conditions. Emergent vegetation, which is of prime importance in the assessment of river habitat quality can be mapped, as can the pool-riffle structure, another important in-stream feature. Again, using a time sequence of photographs, changes within the river can be monitored, which may even include variations in the position of the river itself.

The multi-level approach to mapping the river corridor can be used to provide information or enhancement opportunities to the habitat quality of the river system. The restoration of oxbows and the creation of wetted berms are two conservation techniques whose potential can be assessed using air photo interpretation and which can provide considerable enhancement to the habitat of the flood plain. Riverbank trees can also be mapped using air photo interpretation. Depending on the scale used, individual tree crown and species can be mapped providing valuable information on the bank stability and habitat value. Bankside planting schemes can be initiated from the results of such an airborne survey, providing the ability to easily access priority areas. Conservation staff will be able to use the results of air photo interpretation to evaluate many types of planning applications. For instance, in areas where urbanisation has proved damaging to the river corridor, further large scale development may be blocked. Similarly, areas in which large scale deforestation has occurred reducing habitat value and in-stream quality, protection of surviving woodland may be considered a priority.

Air photo interpretation is therefore a valuable technique for use in river corridor assessment for conservation purposes. It can achieve a level of cover impractical, if not impossible, from ground survey as well as being able to provide considerable detail where required.

Several methodologies are used, starting with the use of stereo photography for interpretation purposes from which a photo overlay is created. The overlay is the either used create a plot overlay to existing mapping to be used for scanning and processing. Alternatively, the plot is used for reference for use with on-screen digitising to either a map or digital photographic backdrop. In either case, the resulting datasets can be provided in a number of formats.

Figures 6.10 and 6.11 show an aerial photograph and a river corridor assessment / habitat survey of the River Ray catchment area, as an example of this methodology.

Figure 6.10 Aerial Photograph of the River Lynher, near Tremaston in Cornwall.

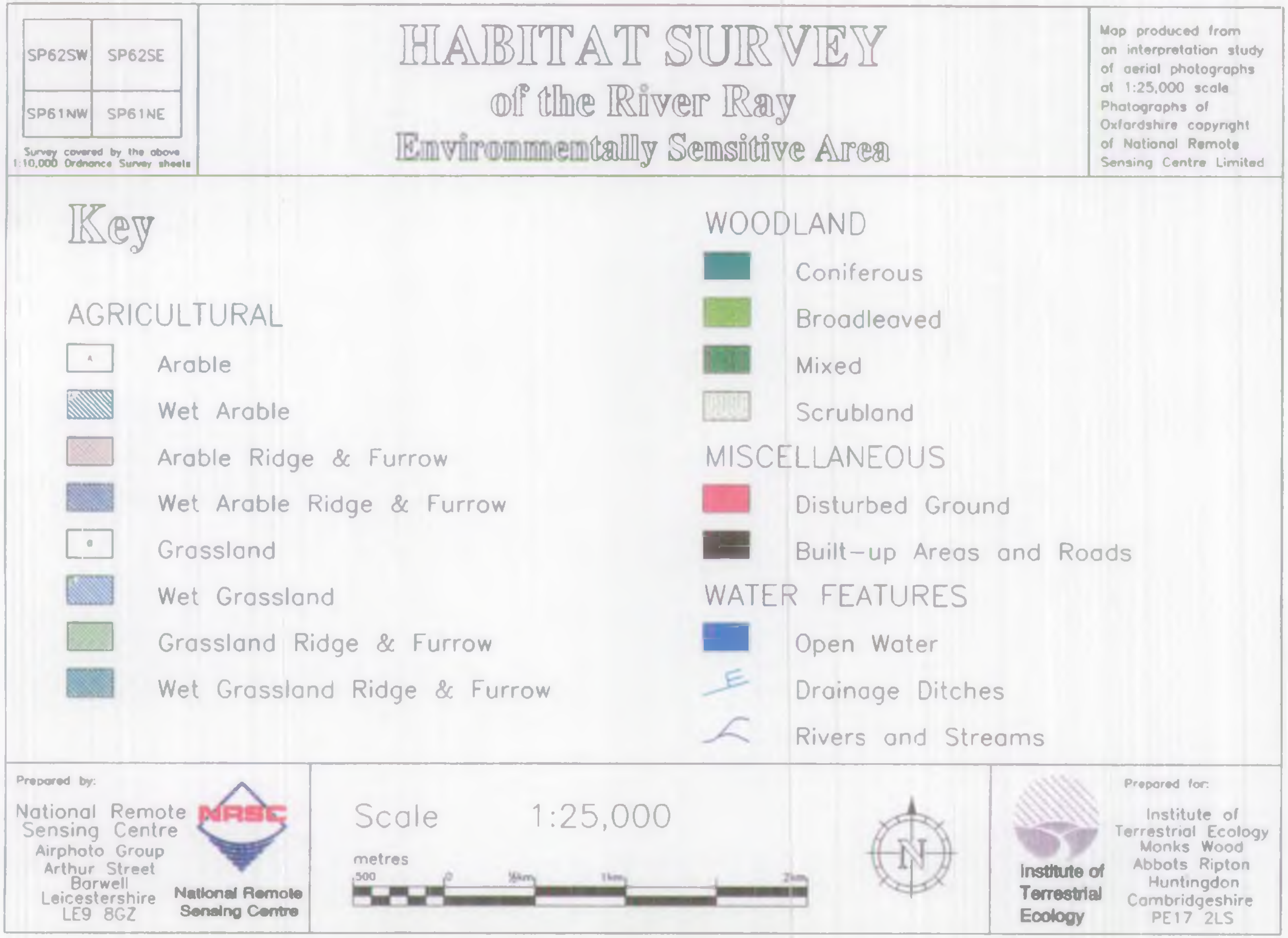

Figure 6.11 Habitat Survey/River Corridor Assessment

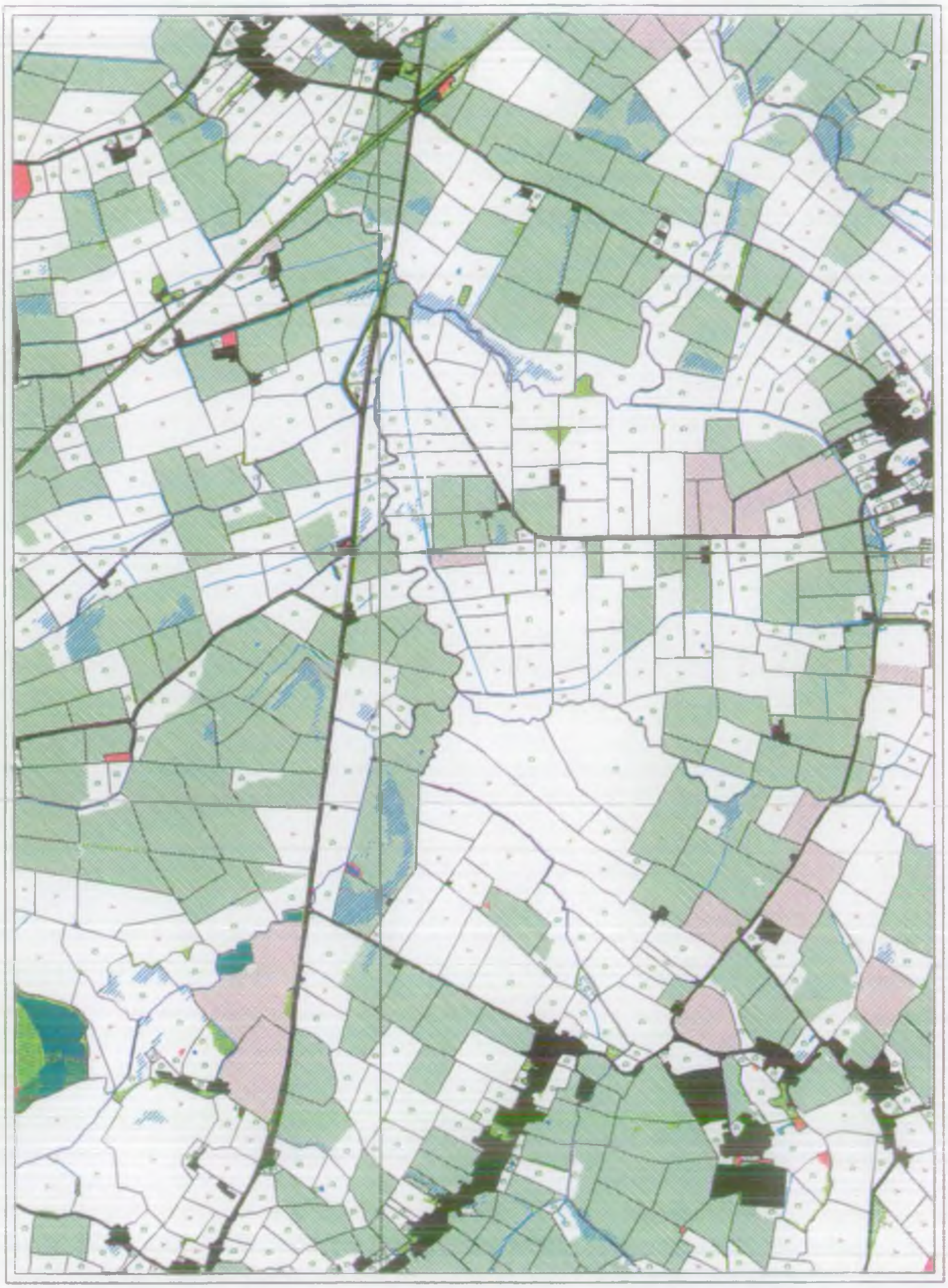

Figure 6.11 Habitat Survey/River Corridor Assessment

6.6 FISHERIES

6.6.1 Introduction

One of NRA's aims is to maintain, improve and develop fisheries. This aim is closely linked to the water quality strategy and there are a number of ways in which remote sensing can help. NRA is responsible for both inland and coastal fisheries out to the three mile limit from the shore. Remote sensing has a role both in fisheries monitoring and management.

6.6.2 Marine Fisheries

Studies of total suspended matter (seston), yellow substance, chlorophyll and macrophyte surveys are all possible. Sea surface temperature (SST) maps from NOAA AVHRR are used by salmon and tuna fleets, some tuna feed on the warm seaward side of thermal fronts while salmon feed on the cold landward side. Physical features such as gyres, eddies, inversions and upwelling, important to fisheries can also be detected using SST maps.

6.6.3 Inland Fisheries

The same procedures can be applied to estuarine waters and further applications such as investigations of the mixing of fresh and saline waters are possible. Kelp and macrophyte surveys are also possible as outlined in the vegetation mapping section. Perhaps more important in the enclosed waters of an estuary or harbour is monitoring and controlling pollution. Remote sensing combined with marine survey is an extremely good method of assessing pollution problems. For more information on this subject you are referred to the NRA R&D report 4, Airborne Remote Sensing of Coastal Waters.

Further upstream the spatial resolution of the data must be greater and only airborne survey will be applicable. Fisheries habitat mapping, river morphology studies, investigations of water mixing zones and pollution sources are all possible.

6.7 NAVIGATION

6.7.1 Introduction

The NRA aims to improve and maintain inland waters and their facilities for use by the public where the NRA is the navigation authority. This involves an extensive, continuous programme of repair, maintenance and licence enforcement. Inland water navigation is dependent on the river or channel depth and morphology which is in turn dependent on the flow and sediment transport within the system.

Riverine and estuarine morphology can be studied both by satellite imagery and airborne data as detailed below. Bathymetric mapping is also possible using satellite imagery in the visible bands, however its use is restricted by water quality, and is not recommended in waters with high levels of suspended sediment. As an alternative ERS-1 SAR is also being investigated for bathymetric mapping.

6.7.2 Riverine and Estuarine Morphology

Remote sensing is an appropriate method of monitoring riverine and estuarine morphology, sandbanks and mudflats, perhaps to provide warning when maintenance dredging is required. Both satellite and airborne data are suitable depending on the scale required.

Landsat Thematic Mapper was used to investigate the sandbanks in the Mersey Estuary when consideration was being given to whether to construct a tidal power barrage. Studies included determining the flow and sedimentation patterns within the estuary and the prediction of any changes caused by a barrage. However, in order to model the flow in the estuary it was necessary to determine the location of existing sandbanks. The most recent ship surveys were in 1977 and 1984, Landsat imagery for 1988, when the study was taking place, was available.

Band TM4 of Landsat data is in the infra-red part of the electromagnetic spectrum and is therefore absorbed strongly by water but not land. Therefore this band was density sliced in order to discriminate between the water and sandbank. To compare the new 'satellite' survey with earlier ship surveys, the bathymetric data were converted into digital terrain models, (digital elevation models). Figure 6.12 shows a composite of bands TM2, TM3 and TM4 produced to show the location of sandbanks and the distributions of sand, mud and vegetation. If height data are required the alternatives are to use multiple images at different states of the tide or possibly SPOT stereo-pairs to produce a digital elevation model. Multiple images should be obtained over a short period to ensure as few changes in the sandbanks as possible in the interim.

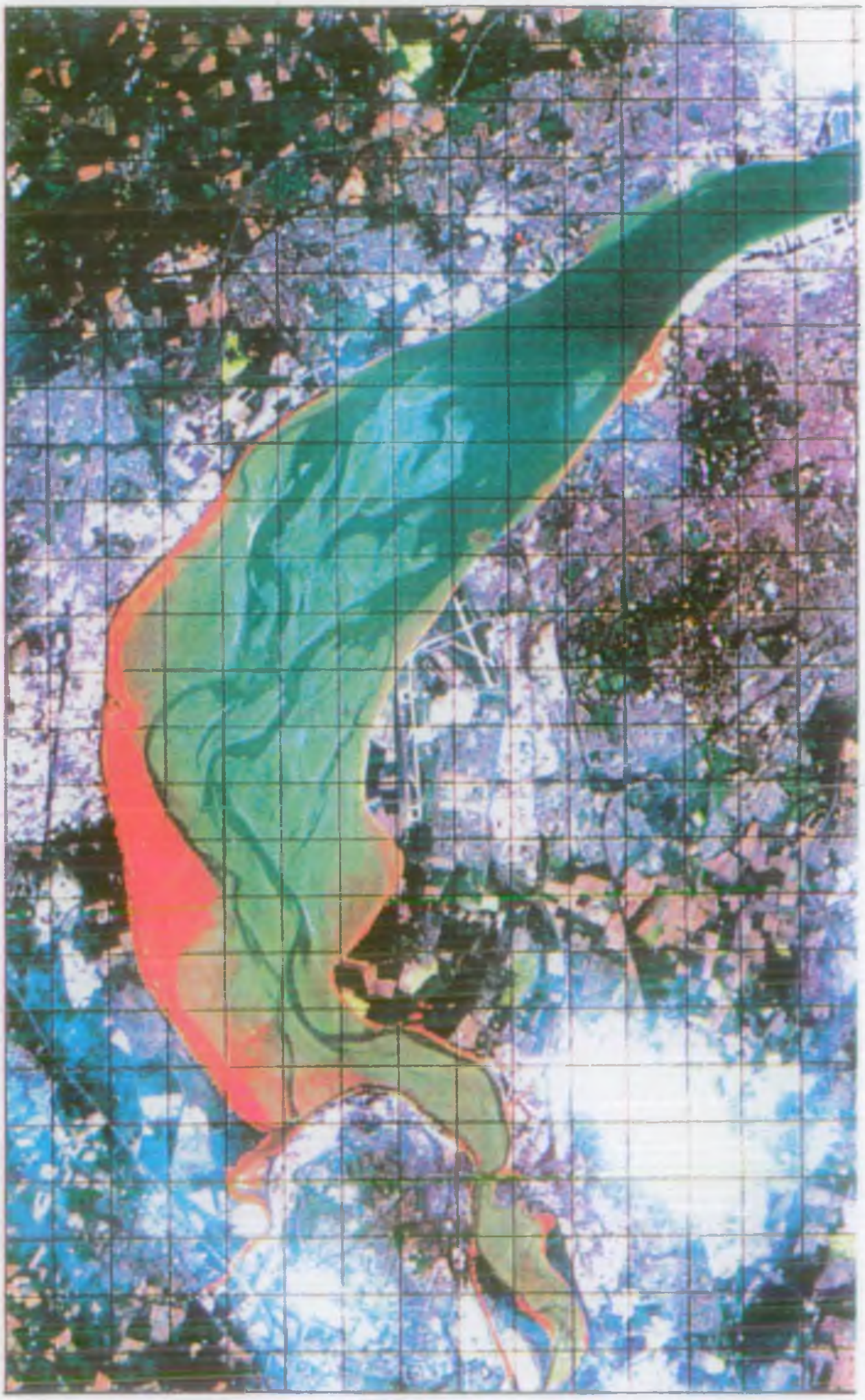

Figure 6.12 Sandbanks in the Mersey Estuary

6.7.3 Bathymetric Mapping

Satellite bathymetric mapping utilises the visible bands of either Spot or Landsat TM. These bands penetrate coastal waters up to a maximum of about 25 metres. The infra-red band is used to mask out the land and a depth inversion algorithm applied to the sea data. Sea truth in the form of recent echo sounder data or a bathymetric chart is used to correlate depth values to the digital numbers in the image. This system means that even if only a small area of sea truth is available the depth information can be extrapolated over the whole image.

However if high concentrations of suspended sediment exist in the water it is their signature and not the bottom topography that is seen in the image. It is generally considered that UK waters are too heavily laden with sediment for this system to work as it does with great success for example in the Arabian Gulf. Instead Synthetic Aperture Radar signatures are being investigated for their bottom topography information. Although the radar beam does not penetrate the water the topography is reflected by the surface wave signature in waters shallower than approximately 50 metres. A knowledge of local currents and wind effects at the time of imaging is required in order to extract the bottom topography.

Section No.7
Conclusion

NRA applications of remotely sensed data are extensive. This report has been produced to serve as an introduction to the subject and highlight examples of RS data use within the NRA. It can also serve as a reference manual for NRA personnel hoping to acquire data for a particular project. Details of the data available, their characteristics and uses can be determined from this documnent. The procedure for acquiring data and and their suitability in terms of cloud cover and areal coverage which is defined in the search results are also explained. Armed with this information and any futher advice required from NCIMS it is hoped that NRA personnel will have the necessary knowledge to organise research and monitoring projects which require a remote sensing input.

Whether investigating, planning for, contracting out, or undertaking a remote sensing project, NRA's National Centre for Instrumentation and Marine Surveillance (NCIMS) will be able to provide further information, support and advice.

Suggested Further Reading

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Glossary

AATSR : Upgraded version of the ATSR sensor designed for the proposed ENVISAT mission. Acronym for Advanced Along Track Scanning Radiometer. See also, *ATSR/*

Active Microwave Instrument (AMI): Package of active microwave sensors on board ERS-1 comprising the SAR, microwave scatterometer and radar altimeter instruments.

Active Sensor: Sensor which generates its own illumination and measures the return. Cf. *Passive sensor.*

Airborne: Describes a sensor carried on an aircraft, or more generally, any sensor that observes the Earth from within the atmosphere.

Algorithm: Name given to a general method or "recipe" for solving a particular problem, usually the first step in defining the problem and its solution in a logical manner, prior to implementing it on a computer.

Altimeter: See: *radar altimeter.*

AMI: See *Active Microwave Instrument, Synthetic Aperture Radar.*

ANN: See *Artificial Neural Network.*

Arc: A line feature in a GIS defined by joining two nodes. See also, *node, polygon*.

Artificial Neural Network (ANN) A particular computing architecture which mimics the way in which the brain stores and processes information. A n ANN has the capability to "learn" or be "trained" to recognise complex patterns, and has an application in classification procedures. Also known as a neural net.

ATM: General name for one of a series of airborne multispectral scanners with broad wavebands spanning the visible, infra-red and thermal regions of the spectrum. Acronym of Airborne Thematic Mapper.

Atmospheric Correction: Processing an image to remove or suppress the interference caused by the atmosphere.

ATSR: Passive scanner on the ERS-1 spacecraft, working in the infra-red and microwave regions of the spectrum. Acronym of Along Track Scanning Radiometer.

ATSR-2: Upgraded version of the ATSR installed on the ERS-2 spacecraft.

Attribute: A value or code associated with a feature in a GIS. For instance, a line representing a road might have attributes describing the width of the road, its status and average volume of traffic associated with it.

AVHRR: Passive, mainly infra-red and thermal sensor carried on the NOAA series of spacecraft. Used mainly for meteorological and sea surface temperature studies. Acronym of Advanced Very High Resolution Radiometer.

Bit: Fundamental unit of information storage in a computer or storage medium. The bit number is also used to describe the range of available values (or DN's) in a data set. Short for "binary digit". See also *byte*, *pixel depth*, *digital number*.

Bit Number: See *Pixel Depth*.

Buffer Zone: Region defined around a feature in a GIS dataset, which can be used to include or exclude other features or areas in other coverages.

Byte: Common unit of data storage. 1 byte = 8 bits.

Canonical Component: Synonym for principle component. See *Principal Component Analysis (PCA)*.

Case 1 waters: Waters generally found in deep ocean, far from land, containing mainly chlorophyll and related pigments. Cf. *Case 2 waters*.

Case 2 waters: Waters generally found in coastal and estuarine regions containing suspended sediment, yellow substances and man-made pollutants, in addition to chlorophyll and related pigments. Cf. *Case 1 waters*.

CASI: Airborne multispectral scanner with very high spectral resolution (approximately 280 wavebands spanning the visible and near infra-red). Acronym of Compact Airborne Spectrographic Imager.

CCD: See: *Charge Coupled Device*

CCT: See: *Computer Compatible Tape*.

CD-ROM: Device for storing data on an optical disk, similar in form to a conventional audio compact disk. Data on a CD-ROM cannot be changed or erased. Acronym of Compact Disk Read Only Memory. See also *optical disk*, *WORM*.

Charge Coupled Device (CCD): Electronic sensor which produces a voltage roughly proportional to the amount of light or other radiation falling on it. Widely used in digital scanners as the electronic equivalent of photograhic film.

Classification: The process of dividing up an image into different areas.

Composite: See *RGB Composite.*

Colour Composite: See *RGB Composite*

Colour Space: Conceptual three dimensional space used to analytically describe a colour in terms of the relative amounts of red, green and blue which make up that colour.

Computer Compatible Tape (CCT): Data storage medium consisting of a 12" reel of magnetic tape. Described in terms of bytes per inch (bpi) of tape.

***Contrast Stretch*:** See *histogram stretch.*

Convolution: The mathematical process of applying a kernel or filter to a digital image.

Coverage: Term used to describe a dataset within a GIS, with a particular theme, such as land use, geology, water courses, etc. Also called a *thematic layer.*

CZCS: Digital scanning instrument, designed specifically for ocean colour studies, carried on the Nimbus-7 satellite between 1978 and 1986. This sensor became one of the foundations of ocean colour remote sensing studies, and the forthcoming SeaWiFS sensor is designed to continue its work. Acronym for Coastal Zone Colour Scanner. See also *SeaWiFS.*

DEM: See *Digital Elevation Model.*

Digital Data: Data which is stored as a series of numbers in a computer memory or on a storage medium, such as a CCT, as opposed to being stored as a visual image such as a photograph.

Digital Elevation Model (DEM): Raster dataset, where the value in each pixel reflects the height of the land at that point. At large scales, the DEM will reflect the tops of buildings, forested areas, etc., rather than the true ground level. Cf. *Digital Terrain Model.*

Digital Number (DN): A value generated by a digital scanner which relates directly to the amount of radiance it records. The range of DN values available is governed by the dynamic range of the sensor, but is generally between 0 and 255. The lowest amount of radiance detectable by the sensor generates a DN of 0. The largest amount the radiance can handle (and radiance levels above this) generates a DN of 255. Intermediate levels of radiance generate a DN from 1 to 254. The term DN is also used to refer to the value stored in each pixel of an image.

Digital Photo: Digital images datasets produced by scanning vertical colour aerial photographs, and producing a georeferenced "mosaic" at a specified scale. See also *Orthophoto.*

Digital Scanner: A sensor which records a scene directly as digital data using electronic components, as opposed to producing a photographic image on film. See also: *pushbroom scanner, whiskbroom scanner.*

Digital Terrain Model (DTM): Type of DEM, which reflects the true ground level as opposed to the top of the land cover. Also refers to a DEM where the land cover type is coded along with the elevation of each pixel. See also *Digital Elevation Model (DEM).*

DMSV: Airborne multispectral sensor, recording on standard video tape in four bands. Acronym of Digital Multi Spectral Video.

DN: See: *Digital Number.*

DTM: See *Digital Terrain Model.*

Dynamic Range: The range of values of DN available in a dataset, usually describe in terms of the number of bits used to store the information from one pixel of the image. For example, 8-bit data has a dynamic range of 0-255. 16-bit data has a dynamic range of 0-65,535.

Earth Observation (EO): Alternative name for remote sensing, also used to describe an application looking specifically at the surface of the Earth from space.

Earth Observing System (EOS): System proposed by NASA as part of its "Mission to Planet Earth" programme, consisting of a number of satellites carrying complimentary instruments to investigate all aspects of the environment of the Earth. The MODIS sensor will be part of this system. See also *MODIS.*

Edge enhancement: An image processing operation which emphasises "edges" in an image, for instance, boundaries between fields, roads, coastlines, etc.

Emitted Infra Red: Synonym for *Thermal Infra Red.*

ENVISAT: Comprehensive Earth Observation satellite planned by ESA for launch in 1998. ENVISAT will carry numerous instruments for several remote sensing applications, including the MERIS imaging spectrometer. See also *MERIS*, *AATSR*.

EO: See *Earth Observation*.

EOS: See *Earth Observing System.*

ERS-1: Remote sensing and earth observation satellite built by ESA and launched in 1991. Carries both active (SAR) and passive (ATSR) sensors. Acronym of European Remote sensing Satellite.

ERS-2: Successor spacecraft to ERS-1, launched in April of 1995. Carries ATSR-2, an upgraded version of ATSR, along with a suite of active microwave instruments similar to those on ERS-1.

ERTS: Initial name for the early LANDSAT satellites (1, 2 and 3) between 1972 and 1975, when ERTS-A was renamed LANDSAT-1. Acronym for Earth Resources Technology Satellite.

ESA: European Space Agency.

Exabyte: Type of HDDT; term also used as a synonym for HDDT. See: *High Density Data Tape.*

False colour composite: A colour composite which does not simulate the way the human eye would perceive the scene, e.g. by displaying infra-red bands in the colour channels instead of visible bands. See also: *colour composite, true colour composite*.

Feature space: See: *scattergram*

Field of View: Area from which a sensor can receive (or "see") radiance.

Filtering: Generic name for an image processing operation which works on small groups of pixels within an image, for example, taking the average DN of a block of pixels.

FLH: See *Fluorescence Line Height.*

FLI: See *Fluorescence Line Imager.*

Fluorescence: The property of certain materials whereby light energy is absorbed at a certain wavelength and then re-emitted a short time later at a different wavelength, usually longer. See also *Laser Induced Fluorescence (LIF), Fluorescence Line Height (FLH).*

Fluorescence Line Height (FLH): Peak, or line, seen in the spectrum a fluorescing substance such as chlorophyll, corresponding to the wavelengths at which fluorescence occurs. The relative height of this peak compared to the wavelengths either side of it can be used as an indication of the amount of that substance present. See also *Fluorescence Line Imager (FLI).*

Fluorescence Line Imager (FLI): Passive airborne multispectral scanning system with very narrow wavebands, designed specifically to detect chlorophyll fluorescence lines , and so map chlorophyll distribution in water. The FLI scanner was the predecessor of the CASI system.

Footprint: The area of the Earth's surface observed by a satellite, aircraft or sensor. See also *IFOV, Field-of-View.*

Fourier Transform: Mathematical image processing operation which converts a visual image into its component spatial frequencies. Applications include removal of noise or interference from an image.

GCP: See: *Ground Control Point.*

Gelbstoffe: German term, meaning literally "yellow stuff", used to describe organic substances (such as humic acid) resulting from the decomposition of vegetation and dissolved in water.

Geocoding: The process of placing an image in a specific map projection, by assigning latitude / longitude or easting / northing coordinates to each pixel.

Geographic Information System (GIS): A computer database for storing, manipulating, analysing and displaying geographically or spatially referenced information.

Geostationary orbit: Orbit in which a satellite circles the Equator at a distance of about 36,000 km. At this distance, the time for the satellite to complete one orbit is exactly the same as the time the Earth takes to rotate once on its axis, so the satellite appears to remain stationary over the same point on the Equator. This is the favoured orbit for telecommunications satellites, and some weather satellites such as METEOSAT, but is generally at to remote a distance to permit detailed earth observation studies. Cf *polar orbit.*

GIS: See *Geographic Information System.*

Global Positioning System (GPS): Generic name for a number of operational systems which enable the location of a point on the Earth's surface to be fixed to an accuracy of about 10 metres.

GOES: Series of geostationary earth observation satellites, operated by NOAA, beginning in 1974, with a variety of functions primarily in ocean and atmospheric research. Acronym of Geostationary Operational Environment Satellite.

GPS: See *Global Positioning System*.

Graphic User Interface (GUI): A way of enabling an operator to run a computer program (or suite of computer programs) by pressing "buttons" and icons on the screen rather than typing in commands from the keyboard.

Greyscale: A method of displaying digital image data as a picture on the computer screen. Each DN is assigned a shade of grey (conventionally, DN 0 as black up to DN 255 as white). The result appears the same as a black-and-white photograph of the scene. See also: *pseudocolour*.

Ground Control Point (GCP): A feature in an image, such as a road junction, for which the geographical coordinates are known to a desired degree of accuracy. These are used to geocode an image. See also *geocoding*.

Ground Truth: Generic term describing prior knowledge of the area of the earth represented in a remote sensing image, such as what ground cover types are present. This is most commonly used as an aid to classification. See also *sea truth*.

GUI: See: *Graphic User Interface*.

Hardcopy: A permanent record of a remote sensing image, or value added product, such as a photographic print, or printout from a laser printer.

HDDT: See: *High Density Data Tape*.

Header File: A file which accompanies the remote sensing data on a tape, containing some ancillary information about the data, e.g. date and time the scene was acquired, name of the sensor, geographic coordinates of the corners of the image.

High Density Data Tape (HDDT): Data storage medium comprising magnetic tape in a small cassette cartridge, similar to cassettes used in hand held video cameras and camcorders.

High Level Feature: An entity in an image which corresponds to some feature or structure in the real world (such as a field, road, building etc.), which is composed of lower level features such as edges, lines and individual pixels. Cf. *low level feature.*

High-Pass Filter: Filter which emphasises features such as edges in an image. See also *Edge enhancement.*

Histogram Equalisation: A specific sort of histogram stretch, such that the end result is that the average number of pixels in each greyscale level is equal to the number of pixels in the image divided by the dynamic range. This is an approximation to an "ideal" contrast balance.

Histogram Matching: Histogram operation which forces the histogram of one image to have the approximately same distribution as the histogram of another image. This is used to allow comparison between images of the same scene acquired under different illumination conditions.

Histogram Stretch: Operation which spreads out the "bars" of an image histogram in order to fully utilise the dynamic range, and improve contrast in the image.

HRGB Composite: An RGB composite of the Hue components of three colour images; a method of combining the spectral information of nine different bands together in one colour image. See also *Hue - Saturation - Intensity, RGB composite.*

HRV: Sensor carried on board the SPOT series of satellites. Acronym for High Resolution Visible detector. See also: *SPOT.*

HSI: See: *Hue - Saturation - Intensity*

Hue-Saturation- Intensity (HSI): An alternative way of analytically describing a colour, in terms of the Hue of the colour (basic colour), the paleness of the colour (saturation) and the brightness of the colour (intensity). See also: *red-green-blue (RGB).*

Hyperspectral Dataset: Term used to describe the type of dataset generated by an imaging spectrometer, i.e. a multispectral image in a very high number of narrow wavebands. Typical uses are extraction of spectral signatures and classification. See also *CASI, Imaging Spectrometer.*

IFOV: See: *Instantaneous Field Of View.*

Image Processing System: A computerised system or suite of computer programs for performing various mathematical and statistical operations on digital image data.

Image Segmentation: Process of dividing up an image into a collection of features, on the basis of common characteristics, such as DN distribution, texture, tone, etc. These features can be classified with a greater accuracy than by consideration the spectral response of individual pixels alone.

Imaging Spectrometer: Sensor with very high spectral resolution, which can record an image in a very large number of wavebands. Imaging spectrometers are currently mainly airborne instruments, but spaceborne versions are planned for future earth observation satellites. See also: *CASI.*

Instantaneous Field of View (IFOV): The small area of the Earth observed at any instant by a scanner as it scans out the image. Each IFOV generally corresponds to one pixel in the image.

Kernel: A "window" of pixels which specify a filtering operation such as smoothing or edge enhancement. See also *convolution*.

LANDSAT: Series of Earth observation satellites launched by NASA, beginning in 1972. Early LANDSAT spacecraft (originally called Earth Resources Technology Satellites, or ERTS) carried MSS and RBV sensors. The present satellite, LANDSAT-5, carries MSS and TM sensors.

Laser: Device which generates a beam of light, usually in the ultra violet, visible or infra-red regions. Light from a laser is very intense, and has the property that it does not spread out like light from a conventional source, but remains in a very narrow, tightly defined beam over very large distances.

Laser Fluorosensor: See *Fluorescence Line Imager (FLI).*

Laser Induced Fluorescence (LIF): Stimulation of a substance, such as chlorophyll, to fluoresce by means of a laser operating at the appropriate wavelength.

LIDAR: An active airborne sensor which works in a manner analogous to a radar but using a laser beam rather than microwaves to provide illumination. Uses include bathymetry, vegetation and air pollution studies. Acronym of Light Detection And Ranging. See also *Fluorescence Line Imager (FLI), Laser Fluorosensor.*

LIF: See *Laser Induced Fluorescence.*

Look-Up Table (LUT): Table used in a histogram manipulation which, for each DN value in the original histogram, the corresponding DN value in the manipulated histogram.

Low Level Feature: Component of an image, such as an edge or individual DN values, which is a component of a larger feature, such as a field or road. Cf. *High Level Feature.*

Low-Pass Filtering: See *smoothing.*

LUT: See: *Look-Up Table.*

MERIS: Spaceborne imaging spectrometer instrument, to be carried on the proposed ENVISAT spacecraft. MERIS will be specifically designed for ocean colour applications, but will also be used for atmospheric and land use studies Acronym of Medium Resolution Imaging Spectrometer.

METEOSAT: Series of geostationary weather satellites operated by ESA, launched between 1989 and the present. Provides coverage of the full Earth every half hour.

Micrometer: See *Micron.*

Micron (μm): Unit of measure equal to 0.001 mm, or one millionth of a meter. Commonly used to express wavelengths in the UV - visible - infra-red range, for example, the visible band is between 0.4 μm and 0.7 μm. See also *nanometer.*

Microwave: Region of the electromagnetic spectrum with wavelengths between about 1 mm and 1 m (1,000 μm - 1,000,000 μm). This merges into the radio wave region. Microwaves are used primarily in radar and SAR systems, although some passive microwave sensors are used experimentally.

Microwave Scatterometer: Active sensor which measures the amount of microwave radiation backscattered from the surface. This has applications particularly in determining wind speed and direction over the oceans. A particular instrument of this type is carried on board ERS-1.

Middle Infra-red: Region of the electromagnetic spectrum between NIR and the thermal band (about 2 μm - 5 μm wavelength). Middle Infra-red can reflect soil parametres such as moisture content. Also referred to as Short Wave Infra Red (SWIR).

MODIS: Spaceborne imaging spectrometer type instrument, proposed as part of NASA's forthcoming Earth Observation System. MODIS is due for launch around 1998. Acronym for Moderate Resolution Imaging Spectrometer. See also *Earth Observing System.*

Mosaic: Joining together of a number of remote sensing images in a common map projection and reference system, in order to form a complete coverage of an area larger than a single image.

MSS: Passive multispectral sensor carried on LANDSAT spacecraft. Now superseded by Thematic Mapper. Acronym for Multi Spectral Scanner.

Multispectral Analysis: Method of interpreting remote sensing data which examines the way the reflectance of a scene varies from one waveband to the next. This approach forms the basis of many applications of remote sensing, such as land cover mapping and water quality determination.

Multispectral Dataset: An image of the same scene acquired in several different wavebands. The images from each individual waveband are usually stored together in a one file on computer tape. See also *hyperspectral dataset*.

Nadir: Point on the Earth's surface directly below the satellite.

Nanometer (nm): Unit of measure equal to 10^{-9} metres (or one millionth of a millimeter). Commonly used as an alternative to the micron (µm) to express wavelengths in the UV - visible - infra-red region. 1 µm = 1000 nm so, for example, the visible band is 400 nm to 700 nm. See also *micron,*.

NASA: American National Aeronautical and Space Administration.

NDVI: See: *Normalised Difference Vegetation Index*

Near Infra Red (NIR): Region of the electromagnetic spectrum at slightly longer wavelengths than visible red light, generally taken to be between 0.7 µm and 1 µm. Green vegetation is highly reflective at these wavelengths.

Neural Net: See *Artificial Neural Network (ANN)*.

Nimbus: Series of meteorological satellites operated by NASA, launched between 1964 and 1978. The last satellite in the series, Nimbus-7, carried the CZCS sensor (ceased operation in 1986), and an ozone sensor which is still operational.

NIR: See *Near Infra Red*

NOAA: Series of meteorological satellites, which since 1978 have carried the AVHRR sensor. Acronym for National Oceanographic and Atmospheric Administration, the organisation which operates the satellites.

Node: A point feature in a GIS, for instance, defining the position of a well, building or pylon. See also *arc, polygon*.

Noise: Random fluctuations and errors in an image, from a variety of sources, manifested as, for example, haziness, grainy appearance, "holes" in an image, or the appearance of stripes across a scene. Afflicts all remote sensing images to some degree, but can usually be removed, or at least suppressed, through a variety of image processing techniques.

Normalised Difference Vegetation Index (NDVI): A standard number indicating the amount of green vegetation present in a given pixel of an image. It is computed from a number of bands in a remote sensing image so as to compensate for illumination effects, and allow direct comparison between different images.

Ocean Colour: General name for the field of remote sensing which interprets the "colour" of water bodies (i.e. the amount of radiance emerging from the water at a number of different visible wavelengths) in terms of various water quality parametres, such as suspended sediment or chlorophyll concentration.

Optical Disk: Data storage medium similar in appearance to a conventional audio CD, where data is stored on a reflective disk, and read with a laser. Optical disks come in a number of sizes and capacities, but can generally store several hundred megabytes of data. See also *CD-ROM, WORM.*

Orthophoto: Digital vertical aerial photograph processed to remove geometric distortions caused by variations in the topography of the ground. The result is a cartographically accurate image, where every point appears as if viewed from directly above.

Path Length: The length of the route traversed by radiance measured by a sensor; not necessarily the straight-line distance from target to sensor, since the radiance may be scattered by the intervening atmosphere. This term may also refer to the thickness of atmosphere through which the surface has been viewed.

Passive Sensor: A sensor which simply measures the amount of radiance falling on it, and does not generate its own illumination. LANDSAT Thematic Mapper, and other optical sensors, are examples of passive sensors. Cf. *active sensor.*

PCA: See: *Principle Component Analysis.*

Pixel Depth: The number of shades of grey, or colours, that can be displayed on a computer monitor, usually expressed as the number of bits used to store the data being displayed. For instance, a pixel depth of 8 bits can display 256 shades of grey. See also *bit, byte, dynamic range.*

Pixel: Basic unit in a digital image. The size of the pixel determines the amount of detail that can be seen in an image.

Platform: Generic term for the vehicle which carries a sensor to a position where it can observe its intended target, for example, a light aircraft, balloon, satellite or manned spacecraft.

Polar Orbit: Orbit in which a satellite traverses the globe in a north-south fashion, going close to the poles. A satellite in this orbit can observe almost all of the Earth's surface, as the Earth rotates beneath it. Many earth observation satellites, such as ERS-1 and LANDSAT, operate in polar orbits at a distance of a few hundred kilometres. Cf. *geostationary orbit.* See also *sun synchronous orbit*.

Polygon: An areal feature in a GIS, defined by several arcs. Polygons can represent, for instance, fields and land parcels. See also *node, arc*.

Principal Component Analysis (PCA): Statistical operation on a multi-spectral data set which highlights differences in the *spectral signature* of features in the image. The operation transforms the wavebands in of the dataset into new bands, called principle (or canonical) components, which show up the full range of variance in the distribution of the data. Used, for example, as an aid to discriminating different ground covers or rock types, or as an aid to classification.

Pseudocolour: A method of displaying an image where each DN value is displayed as an arbitrary colour rather than a shade of grey. See also *greyscale*.

Pushbroom Scanner: A scanner which contains a line of electronic detectors, which acquires one line of pixels simultaneously as the platform moves forward. Cf. *whiskbroom scanner*.

Quantization: See *radiometric resolution*.

Quick-look: Small printed or digital version of a satellite image, at greatly reduced detail, which enables one to judge the general quality of the image, for example, the general geographical area covered by the image, or whether particular locations of interest free of cloud.

Radar Altimeter (RA): Active radar instrument carried on ERS-1 which measures the distance the distance between the satellite and the Earth's surface with very high precision (of the order of 10 cm).

Radiance: General term used to refer to the amount of radiation (both visible light, and non-visible wavelengths such as infra-red) coming from a target, which is measured by a sensor and displayed as a shade of grey in an image. Can be thought of as the "brightness" of the target.

Radiometric Correction: Correction of the DN values in raw data received from a satellite to compensate for known effects in a sensor.

Radiometric Resolution: The smallest difference in radiance that a sensor can detect. Also, the difference in radiance which results in a difference of one DN value. Also referred to as *quantization*.

Radar: Active sensor, using microwaves or radio waves to detect objects or acquire an image. Acronym for Radio Detection And Ranging. See also *Synthetic Aperture Radar (SAR).*

Raster: Grid or array of pixels which forms a digital image. Also refers to an array of cells which make up one form of GIS dataset.

RBV: Optical sensor (basically a television camera system) carried aboard LANDSAT satellites in the 1970's. Now superseded by digital scanning systems. Acronym for Return Beam Vidicon.

Red - Green - Blue (RGB): Method of analytically describing a colour, in terms of the relative amounts of red, green and blue which make up that colour. See also: *Hue - Saturation - Intensity (HSI)*

Reflected Infra Red: Synonmym for *Near Infra Red.*

Reflectivity: The proportion of the amount of light (or other radiation) incident on a surface which is reflected away from the surface. In a remote sensing image, surfaces with a high reflectivity appear bright, while surfaces with a low reflectivity appear dark.

Repeat Cycle: Time taken for a satellite to return over the same point on the Earth's surface.

Resampling: Alteration of the position and / or DN value of pixels in an image in order to fit the image to a regular grid fitted to a particular geographical map projection.

Resolution: Smallest change or detail in a parameter which is observable in a dataset. Four quantities important in remotes sensing are: size (spatial), time (temporal), wavelength range (spectral) and brightness (radiometric). See also: *radiometric resolution, spatial resolution, spectral resolution, temporal resolution.*

Retrieval Algorithm: Combination of wavebands and ground truth designed to calibrate an ocean colour dataset in terms of water quality parametres such as suspended sediment or chlorophyll concentration.

Revisit Time: See *repeat cycle.*

RGB Composite: Method of displaying three bands from and image data se on a computer monitor, by superimposing one band displayed in red, one in green, and one in blue. The primary colours add together to create the full range of colours. See also *true colour composite, false colour composite.*

SAR: Active microwave sensor carried by ERS-1. See also: *synthetic aperture radar.*

Scanner: See: *digital scanner*

Scatter plot: See: *scattergram.*

Scattergram: Plot of the DN value of a pixel in one band against the DN value of the corresponding pixel in another band. Used to as simple sort of multispectral classification. The resulting diagram is also known as a *feature space.*

Scatterometer: See *Microwave Scatterometer.*

Sea Truth: Form of ground truth relating to ocean colour studies, in which samples of water are taken and analysed to determine the amount of chlorophyll, suspended sediment, etc.., contained. These values are then used to calibrate remote sensing data. See also *ground truth, ocean colour.*

SeaWiFS: Ocean colour sensor to be launched in 1995 on the SEASTAR satellite. This sensor is the successor of the CZCS instrument, and is designed with a number of spectral bands tailored to studies of chlorophyll and other suspended material in the oceans. Acronym of Sea-viewing Wide Field of view Sensor.

Sensor: Device which records a remote sensing image, by measuring the amount of radiance reflected from the Earth's surface. See also: *digital scanner, active sensor, passive sensor, radiance.*

Short Wave Infra Red (SWIR): See *Middle Infra Red.*

Side -Looking Airborne Radar (SLAR): Airborne radar instrument which acquires an image of a swath of ground to one side of the aircraft's flight path.

SLAR See *Side -Looking Airborne Radar*

Smoothing: The process of replacing the DN of each pixel in an image with the average of the DN's of the pixels around it. This tends to "smooth out" anomalously high or low DN values, and make the image look somewhat blurred. Can be used as a simple method of removing noise. Also known as *low pass filtering*.

Spaceborne: Describes a sensor carried on a spacecraft or satellite above the atmosphere.

Spatial Resolution: Size of the smallest detail which can be observed in an image. For instance, LANDSAT Thematic Mapper has a spatial resolution of 30 metres, which implies that the smallest object that can be seen in an image is 30 metres. Also used to describe the size of the area covered by each pixel in an image.

Spectral Resolution: Wavelength interval to which a sensor responds; also the width of spectral bands of a sensor.

Spectral Band: Synonym for *waveband*.

Spectral Signature: The manner in which the radiance reflected from, or emitted by, a feature changes with wavelength. This is characteristic of that feature (also known as the spectrum of that feature). For instance, green vegetation is highly reflective in the near infra-red band but not very reflective in the visible red. This property can be used to identify vegetation in an image. See also *classification*, *vegetation index*.

Spectrum: See *Spectral Signature.*

Split Window: Method of correction thermal infra-red data for atmospheric effects, by taking measurements at two wavelengths in the thermal infra-red where the absorption properties of the atmosphere are slightly different.

SPOT-PAN: See: *SPOT.*

SPOT-XS: See: *SPOT.*

SPOT: Series of earth observation satellites built by a French / Swedish / Belgian consortium, carries HRV optical sensors, operating in Panchromatic (PAN) and Multispectral (XS) mode. Acronym for Satellite Pour Observation de la Terre. See also *HRV*

Sun-synchronous orbit: Polar orbit such that the satellite crosses points on a given latitude at the same local times each day. See also *polar orbit.*

Supervised Classification: Method of classification which uses some prior knowledge or ground truth, generally with superior accuracy. Cf. *unsupervised classification.* See also: *classification*.

SWIR: Short Wave Infra Red. See *Middle Infra Red.*

Synthetic Aperture Radar (SAR): Active radar sensor which uses mathematical techniques to achieve much higher spatial resolution than is possible with conventional radar. An important instrument of this type is carried on board the ERS-1 satellite.

System Correction: General correction of raw data received from a satellite for various different effects caused by the remote sensing system itself, e.g. distortion of the image caused by the motion of the platform or the action of the scanner.

Tasselled Cap Transformation: Analysis of MSS and TM images of vegetation cover which transforms a set of visible red and near infra-red images into images of soil brightness and vegetation "greeness".

Temporal Resolution: Time interval between successive images of the same area.

Thematic Layer: See *coverage.*

Thematic Mapper: Optical sensor carried aboard later LANDSAT series of satellites, with superior resolution to the earlier Multi Spectral Scanner sensor.

Thermal Band: Synonym for thermal infra-red.

Thermal Infra Red: Region of the electromagnetic spectrum between approximately 3 μm and 10 μm, corresponding to heat radiation emitted by the Earth. Images in this band can be used to deduce surface temperature, particularly at the surface of the sea. Also referred to as the thermal band.

TIROS: Early name for the predecessor series of the NOAA satellites. The first TIROS satellite was launched in 1960. Acronym for Television and Infra Red Observation Satellite.

TM: See: *Thematic Mapper.*

Transfer Function: Mathematical function used in a histogram manipulation which computes the DN value in the altered histogram which corresponds to each DN value in the original histogram. See also: *Look-Up Table (LUT).*

True Colour Composite: A colour composite displaying a combination of bands which approximates the way in which the scene would appear to the human eye. For instance, displaying LANDSAT TM bands 3, 2 and 1 in red, green and blue respectively.

Ultra Violet (UV): Region of electromagnetic spectrum at wavelengths shorter than visible blue light, between about 0.03 µm and 0.4 µm. UV is of limited use in general remote sensing due to the difficulty in manufacturing appropriate optical systems, and also its strong absorption in the atmosphere. UV lasers are, however, useful in mapping oil slicks through fluorescence techniques. See also *Laser Induced Fluorescence.*

Unsupervised Classification: Method of classification based entirely on the statistics of an image, using no other information about the scene. Cf. *supervised classification.* See also: *classification.*

Value Added Product: End result of the interpretation of a remote sensing data set, usually a dataset which shows more information that the original data. For instance, the processing of a thermal-band image of the North Sea into an annotated map of water temperature, showing isotherms in degrees Centigrade. This map is the value added product.

Vector: Method of describing and storing spatial data within a GIS, in terms of points (nodes), lines (arcs) and polygons. See also *arc, node, polygon, raster.*

Vegetation Index: Quantity representing the relative amount of green vegetation in a given pixel of an image, usually expressed as a unitless number. There are a number of different ways of computing a vegetation index from a multispectral data set; the simplest is to divide the near infra-red band by the visible red band. The larger the resulting number, the more vegetation is present. However, this method is influenced by illumination conditions and effects, and so cannot be reliably used to compare different images. See also *Normalised difference vegetation index (NDVI).*

Visible Band: Region of the electromagnetic spectrum between about 0.4 µm and 0.7 µm, corresponding to the range of colours visible to the human eye. Blue light is at the short wavelength end (0.4 µm), up to light red at the long wavelength end (around 0.7 µm).

Warping: Process of distorting an image or dataset (i.e. changing the spatial relationship between pixels) in order to compensate for geometrical effects introduced by the scanner system or motion of the platform. Where this involves fitting the image to a particular map projection or reference system, this process is known as geocoding or geocorrection. See also *geocoding, warping function.*

Warping Function: Mathematical function which maps the row / column coordinates of a pixel in a raw image either to new row / column coordinates in a warped image, or to map coordinates in a geocoded image, e.g.. to latitude / longitude or and easting / northing values.

Waveband: A specific range of wavelengths of electromagnetic radiation which a sensor responds to. Most modern optical sensors can "see" in several wavebands in different parts of the electromagnetic spectrum, normally in the region between visible blue light and thermal infra-red radiation.

Whiskbroom Scanner: A scanner which has only one electronic detector, which sweeps from side to side across the platform's footprint, acquiring one pixel of the image at a time as the platform moves forward. Landsat TM is an example of a whiskbroom scanner. Cf. *pushbroom scanner.*

WORM: Type of optical disk data storage medium, on which data can be written by the user once, but cannot then be subsequently changed or erased. Acronym of Write Once, Read Many. See also *CD-ROM, optical disk.*

Yellow Substance: See *Gelbstoffe.*