Field Techniques Manual:
GIS, GPS and Remote Sensing

- <u>Section B: Data</u>

Chapter 5: Remote Sensing

5 Remote Sensing

5.1 Introduction

Remote sensing involves the use of aircraft or satellites to collect photographs or scanned images of the Earth's surface. Remotely sensed imagery is just one of many types of geographically-referenced datasets that can be processed using a GIS. The origins of remote sensing date back to a photograph taken from a balloon in 1858. By World War I, the aeroplane had become the main platform from which aerial photography was collected. During the inter-war period, film chemicals were developed that allowed colour and infra-red photography: the latter was of particular interest to the military, as it highlighted camouflaged features. Since the 1950s, black and white aerial photography has been the basis of most Earth surface mapping: it still accounts for 99% of all topographic mapping (Petrie 2000). Landsat Earth-observation satellites, operative since 1972, produce digital images in the visible and infra-red parts of the spectrum: each image covers thousands of km^2, with sufficient detail to map many geo-ecological features.

Digital images have many advantages over photographs: digital data can be easily stored and processed by computers, perfect copies of an image can be made in seconds, and digital imagery is readily available for GIS analysis. Over 1999-2000 a new generation of satellites, utilising 'spy-satellite' technology, began to provide commercially-available multi-spectral digital images that could rival the detail obtained by aerial photography. Other recent developments, such as millimetre-precision Global Positioning System (GPS) receivers, improved digital data compression software and Internet transfers of remotely sensed data, have facilitated the use of remotely sensed data in GIS-based projects. The reader should refer to Lillesand & Kiefer (2000) or Drury (2001) for detailed coverage of remote sensing. Techniques for processing and interpreting remotely sensed images are reviewed in Chapter 8.

short wavelength ——————→ long wavelength high frequency ←—————— low frequency
0.4 0.5 0.6 0.7 1.0 10 μm 1.0 mm 1.0 m
visible - **infra-red** - blue green red - **near middle thermal** - microwave - radiowave
<- human eye -> <-------- camera ---------> <----- multi-spectral scanners (MSS) ----> <------- radar -------->

Figure 5-1 The electro-magnetic spectrum and associated sensors (1 μm = 0.001 mm).

The part of the electro-magnetic spectrum that is most widely used in remote sensing extends from the visible wavelengths, through progressively longer wavelengths, to the microwave and radio wavelengths used by radar systems (Figure 5-1). The limited ranges of human vision and conventional photography are apparent. Many features, particularly vegetation and water, show unique variations in the infra-red parts of the electro-magnetic spectrum. Thermal infra-red can be used to detect areas with high rates of evaporation or evapo-transpiration, due to their lower temperatures relative to their surroundings, as well as zones of thermal pollution in water, which could be caused by chemicals or hot water discharges from power stations. Finally, at wavelengths of millimetres to metres, the microwave or radio pulses utilised by radar systems are particularly useful for mapping soil moisture contents and areas of inundation, with the added advantage of being able to ‘see’ through cloud cover. Radar systems are particularly effecting at measuring surface roughness and thereby mapping the texture and shape of features on the surface of the Earth.

5.2 Satellite imagery

Our ability to produce maps of features on the Earth's surface, using remote sensing, is based on the characteristic ways in which different features reflect or emit electro-magnetic radiation. Figure 5-2 illustrates the reflectance responses of various types of Earth surface features: note how each has a unique response, known as its ‘spectral signature’. Vegetation absorbs the red part of the spectrum for photosynthesis, but reflects the green and near infra-red wavelengths for which it has no use, the amount of reflectance varying with, for instance, variations in leaf moisture content, leaf shape and stress due to disease. Bare rock and soil exhibit a great variety of spectral variation, which can be used to determine their mineral composition. The near infra-red part of the spectrum is absorbed by water: this is particularly useful when mapping wetlands, as boundaries between dry land and wet areas are highlighted.

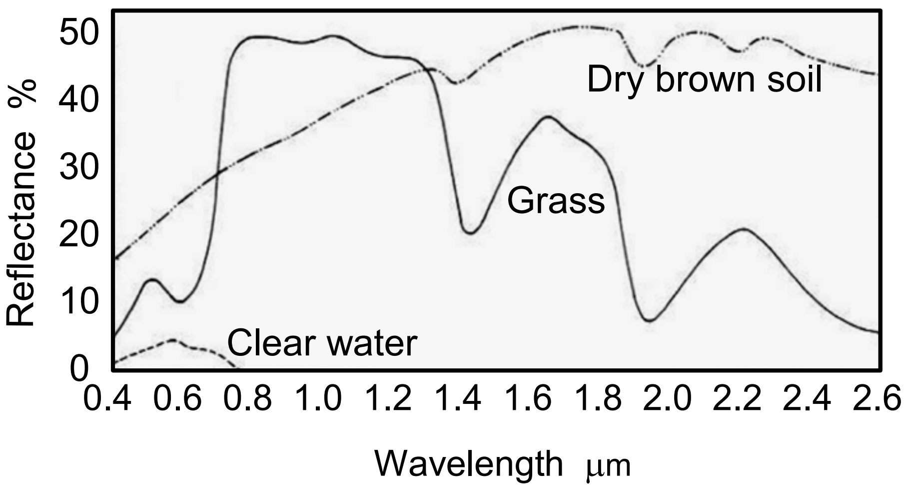

Figure 5-2 Electro-magnetic reflectance curves (‘spectral signatures’) for various surface features.

Multi-spectral scanners detect in the visible and infra-red parts of the spectrum. As we have seen above, each type of land cover feature has a characteristic spectral signature, with peaks and troughs of reflectance dependant on the wavelengths at which electro-magnetic radiation is absorbed and reflected or emitted by that type of feature. An illustration of the sorts of crude spectral signature that can be obtained from a 5-band multi-spectral scanner (MSS) is given in Figure 5-3. Note the general low reflectances with water, the high reflectances with beach sand, the low red / high near infra-red shift with photo-synthesizing vegetation and the corresponding low near-infra-red values in vegetation-depleted urban areas.

Sensors that can detect in hundreds of slices of the electro-magnetic spectrum, known as hyperspectral scanners, allow much more detailed spectral signatures to be collected, greatly improving the identification of different surface features. Most hyperspectral scanners are experimental and are mounted on aircraft (e.g. AVIRIS, CASI, HyMAP), resulting in only limited global coverage, but some space-born systems have recently been launched, notably MODIS (European Space Agency) and HYPERION (NASA).

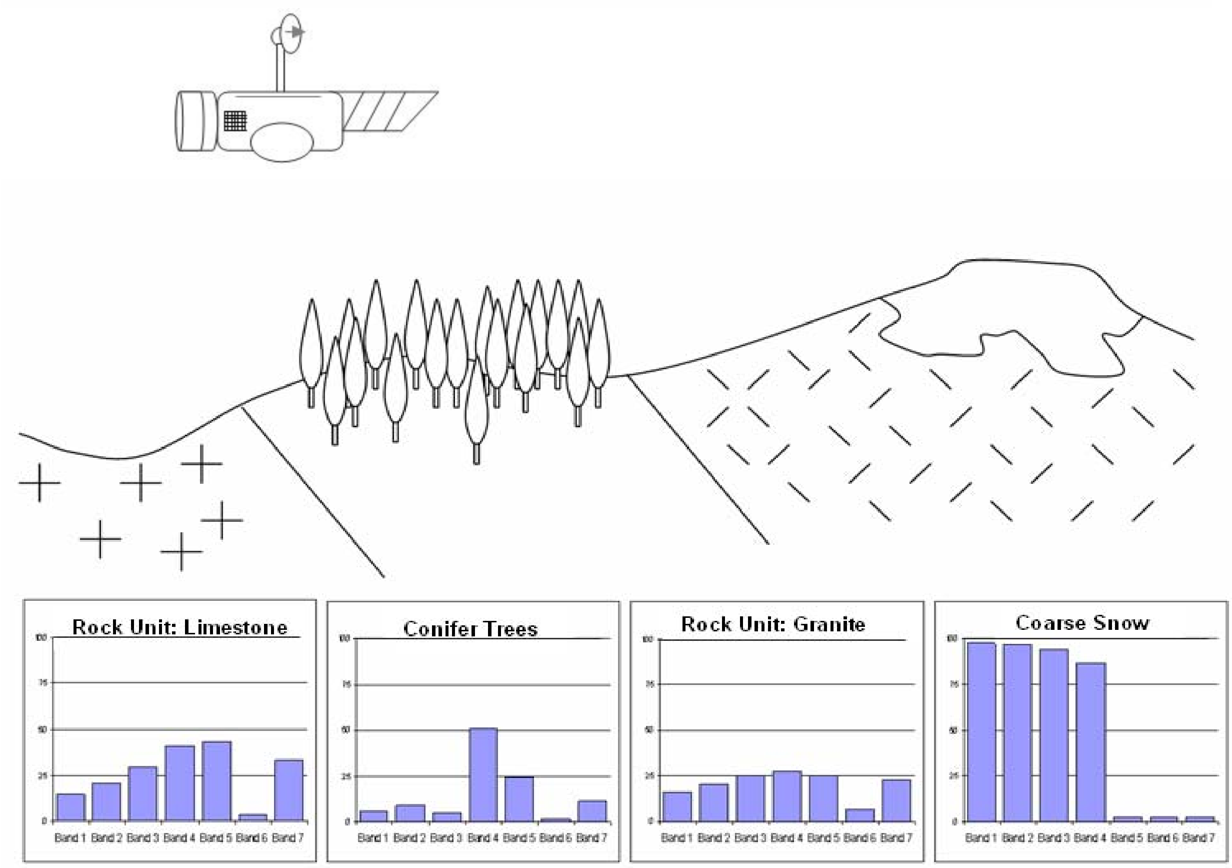

Figure 5-3 Spectral variations, approximating spectral signatures, from a multi-spectral sensor. Band 1 = blue; 2 = green; 3 = red; 4 = near infra-red; 5, 6 = middle infra-red; 7 = thermal infra-red.

5.3 Resolution

When selecting remotely sensed imagery for a given project, the various types of resolution are key considerations (Table 5-1).

Spatial resolution depends on the proximity of a given sensor to the surface of the Earth and the width of each image scene. For instance, the NOAA weather satellites orbit at 833 km: their images are 2400 km wide, with 1.1 km pixels. Landsat TM, orbiting at 705 km, is limited to images that are 185 km wide: consequently it has 30 m pixels. An even better spatial resolution comes from the Ikonos satellite, orbiting at 350 km: its images are only 40 km wide, but they have 1 m pixels. Figure 5-4 shows examples. Remote sensing from aircraft, usually as aerial photography, can provide imagery with resolutions in the 10 cm to 1 m range, allowing detailed mapping.

Temporal resolution is the frequency with which the orbit of a given satellite passes over a location on the Earth's surface. This is an important consideration with features that need frequent monitoring, such as forest fires or algal blooms. The NOAA satellites have a twice-daily temporal resolution, ideal for monitoring, whereas Landsat TM only has a 16-day return period.

Spectral resolution concerns the number of sample-slices of the electro-magnetic spectrum that a given sensor can take: radar satellites currently only sample one slice, or "band"; Landsat TM samples seven bands; and hyper-spectral sensors sample hundreds of bands. The greater the number of spectral bands, the easier it is to automatically map Earth surface features, as their resulting *spectral signatures* will contain more distinguishing details.

Finally, *radiometric resolution* controls the greyscale tonal range of the sensor, i.e. the number of bits into which the recorded energy is divided. Landsat TM produced 8-bit data (i.e. 2x2x2x2x2x2x2x2 = 256 values) with Digital Numbers (DNs) ranging from 0 to 255; while the earlier Landsat MSS only produced 7-bit data, with DNs ranging from 0 to 127.

Table 5-1 Varying spatial, temporal and spectral resolutions of satellite imagery.
(Continued over page)

sensor system		**resolution**		
		spatial	**temporal**	**spectral**
AVHRR weather satellite	visible / IR thermal	1100 m	twice daily	5 or 6 bands: 0.4 - 12.5 μm
Landsat MSS	visible / IR	80 m	16-18 days	5 bands: 0.5-1.1 μm
	thermal	240 m	16-18 days	1 band: 10.4-12.6 μm
Landsat TM & ETM+	visible / IR	30 m	16 days	7 bands: 0.45-2.35 μm
	thermal	120 m	16 days	1 band: 10.4-12.5 μm
Landsat ETM+	panchromatic	15 m	16 days	1 band: 0.52-0.90 μm
SPOT	Visible/near-IR	20 m	26 days, or up to 5 consecutive days	3 bands: 0.5-0.89 μm
	panchromatic	3 m		1 band: 0.49-0.73 μm
	Visible/near-IR	20 m		5 bands: 0.43-1.75 μm
IRS	LISS	23 m	24 days	4 bands: 0.52-0.86 μm
	mid-IR	70 m	24 days	1 band: 1.55-1.7 μm
	panchromatic	6 m	up to 5 days	1 band: 0.5-0.75 μm
	wide field sensor	188 m	5 days	2 bands: 0.62-0.86 μm
ASTER	near-IR	15 m	16 days	3 bands: 0.52-0.86 μm
	mid-IR	30 m	16 days	6 bands: 1.6-2.43 μm
	thermal IR	90 m	16 days	5 bands: 8.12-11.6 μm

sensor system		resolution		
		spatial	temporal	spectral
IKONOS	Visible/near-IR	4 m	11 days: can move	4 bands: 0.45-0.9 μm
	panchromatic	1 m	to new targets	1 band: 0.45-0.9 μm
Quickbird	Visible/near-IR	2.5 m	11 days: or up to	4 bands: 0.45-0.9 μm
	panchromatic	0.6 m	3 consecutive days	1 band: 0.45-0.9 μm
ERS-1 & 2	SAR / raw	12 m	16 to 18 days	C-band radar: 3.8-7.8 cm
	SAR enhanced	20 m	16 to 18 days	C-band radar: 3.8-7.8 cm
RADARSAT	SAR	8 m	24 days, or up to	C-band radar, with
	wide field SAR	100 m	3 consecutive days	4 polarization options

The satellite systems summarised in Table 5-1 are very useful when mapping large-area regional features, such as major river systems, forests, or deserts. Using satellite imagery to map regional features is also very cost-effective in terms of the areas mapped with relative speed and the cost of the imagery per km². Complimenting the regional satellite imagery of the Earth is the Space Shuttle Radar Topography Mission. The SRTM has produced a global set of digital elevation data, based on 90 m pixels, which can be downloaded free from the University of Maryland website (see the weblinks on the CD).

For detailed observations, such as field systems and buildings, use can be made of the panchromatic (grey scale or ‘black and white’) imagery of IRS, SPOT and Landsat, with 5-15 m pixels. The Japanese ASTER satellite is becoming widely used, particularly in studies of geo-hazards, because of (i) its useful spatial and spectral resolutions (see Table 1) allowing effective mapping of soil and rock types; (ii) its ability to produce a 3-D Digital Elevation Model (DEM) of the ground surface; and (iii) its relatively low cost, at US$ 55 for a 60 km x 60 km scene. Another new development is the new generation of modified ‘spy satellites’, such as IKONOS and Quickbird, which have 0.5-2 m panchromatic pixels and 2-5 m multi-spectral pixels, producing images that cover hundreds of square kilometres, with detail that is beginning to rival aerial photography.

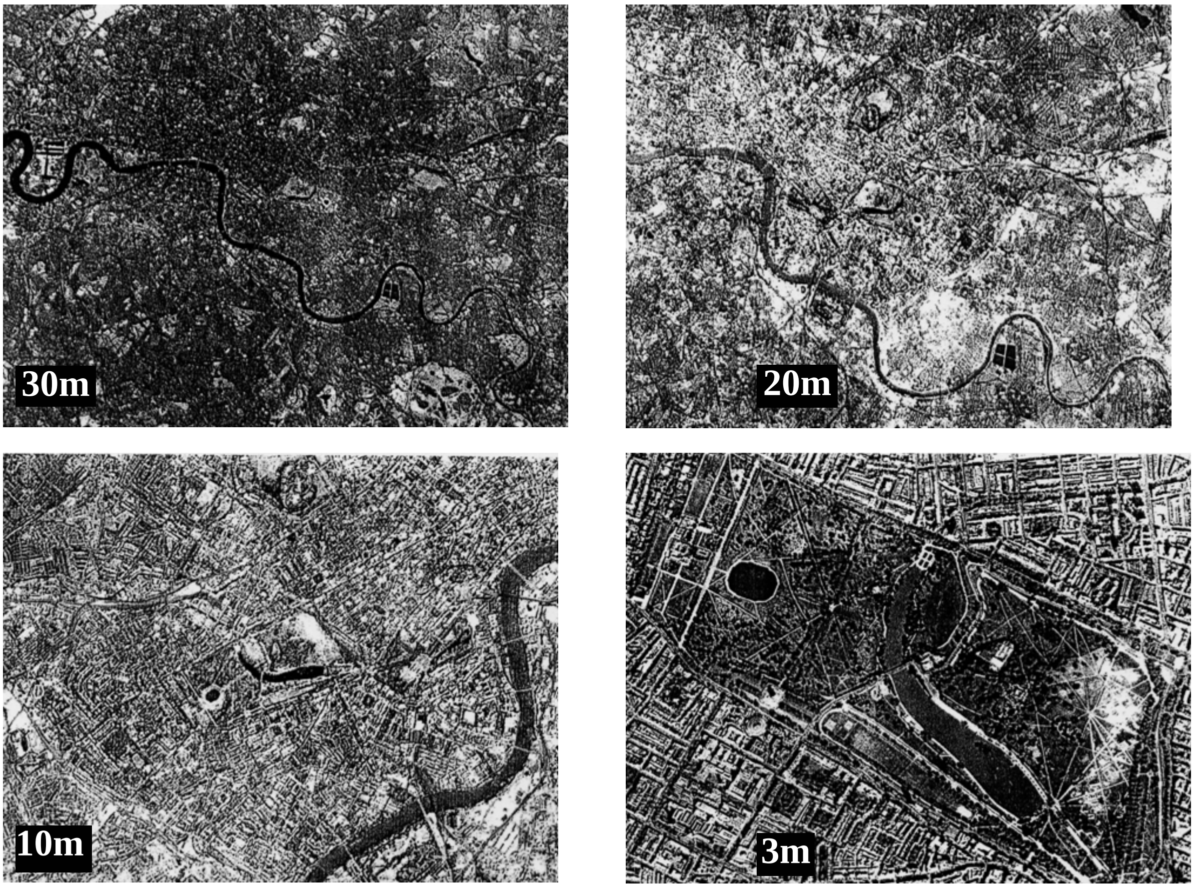

Figure 5-4 Satellite images of varying resolutions: Landsat Thematic Mapper (30 m pixels), SPOT multispectral (20 m pixels), SPOT panchromatic (10 m pixels), and Soviet KVR photo of Hyde Park (3 m). Images courtesy of NPA Group.

5.4 Aerial photography

For more detailed observations and mapping, aerial photography remains the most widely-used method for mapping geo-ecological features and the generation of contour maps via photogrammetry. Identification of vegetation types is easiest using infra-red film: false-colour prints are expensive, but black and white infra-red prints cost little more than panchromatic prints. Conventional aerial photography can be augmented by digital airborne sensing systems (e.g. Milton *et al* 1995). Using digital photography eliminates the loss of time and loss of detail associated with scanning aerial photographs, plus it can be directly utilised by most GIS software. For detailed mapping at scales of 1:10,000 or more, digital photogrammetry looks set to replace conventional photogrammetry, with the arrival of powerful - but affordable - computers and software, notably ERDAS Imagine's Orthomax module. Mount *et al.* (2000, 2003) review digital photogrammetric techniques, in a case study involving river channel changes (see Chapter 9 for detailed coverage of photogrammetry). Also see Plate 1.

With the arrival of relatively low-cost desk-top digital photogrammetry systems, studies of land cover change and dynamic geomorphological processes, such as erosion and landslide activity, have become much easier to carry out. The value of many airphoto archives, some covering the past 50 years or so, is now becoming evident. Many parts of the world are covered by American spy satellite photography, from the late 1950s onwards, notably the

KH series of satellites (available from the US Geological Survey). World-wide coverage of regional-scale Landsat multi-spectral digital imagery, useful for mapping changes in land cover types, dates back to 1972. Bear in mind that large areas of both airborne and satellite imagery may be obscured by clouds, so check cloud-cover details before purchasing. Amongst the negative aspects of aerial photography are the limited aerial coverage of each airphoto and the corresponding high costs (£2-£30/km²). Airborne remote sensing is only feasible when relatively small areas, up to a few hundred km² in size, are to be mapped. In many developing countries, suitable aircraft may not be available and the areas to be mapped may be vast. Such problems have largely been overcome by satellite remote sensing; for instance, each image scene from the most widely used multi-spectral sensor, Landsat TM, covers 31,450 km², with a spatial resolution of 30 m. On a natural resources project in Ghana, re-prints of the only available airphotos, a panchromatic set flown in the 1950s, cost £2/km²; in contrast, digital multispectral Landsat imagery from 1988 cost £0.02/km² and covered the entire region, rather than a few specific sites (Teeuw 1995). A summary of key aspects of remote sensing is given in Table 5.2 and a key to some of the terminology can be found on the following page.

Table 5-2 Key aspects of remote sensing systems.

	AIRBORNE SENSORS					**SATELLITE SENSORS**				
	spectral wavelength									
spectral resolution	**visible**	**NIR**	**MIR**	**TIR**	**micro wave**	**visible**	**NIR**	**MIR**	**TIR**	**micro wave**
• photography	✔	✔				✔	✔			
• laser / LiDAR	✔									
• RADAR					✔					✔
• multispectral	✔	✔	✔	✔		✔	✔	✔	✔	
• hyperspectral	✔	✔								
	limited by cloud cover				all-weather	limited by cloud cover				all-weather
spatial resolution	cm to m (depends on flight altitude)					m to km (depends on orbit altitude)				
temporal resolution	flexible (may be weather-dependent)					0.5 to 35 days (orbit-dependant)				
operational time period	some 1930s archive airphotos; US National Archive WW2 airphotos; most national / regional airphoto surveys are post-1947. 1950+ US spyplane airphotos 1967+ radar surveys (SLAR) 1980+ ATM multispectral 1990+ hyperspectral scanners 1995+ multi-band radar 2000+ LiDAR: laser altimetry (10-50cm contours)					1957-70 CORONA photography 1960+ weather satellites 1972+ Landsat multispectral 1978 Seasat radar 1980+ SPOT visible+NIR 1990 ERS radar, IRS multispectral 2000+ IKONOS, ASTER 2001+ ENVISAT (multi-sensor) 2002+ Hyperion hyperspectral 3m Radarsat 0.6m Quickbird				
approximate cost	varies, depending on flight altitude and processing costs: generally a minimum of US$50 / km²					varies considerably: mostly less than US$ 0.10 / km², but generally with a minimum order of US$100				

Notes for Table 5-2.

remote sensing wavelengths (1µm = 0.001 mm)			
visible	0.4 - 0.7 µm	**NIR**, near infra-red	0.7 - 1 µm
MIR, middle infra-red	1 – 3 µm	**TIR**, thermal infra-red	3 - 15 µm
microwave	1,000-1,000,000 µm (1 mm - 1 m)		

5.5 Radar Imagery

Radar (Radio Detection and Ranging) initially used radiowaves to determine the distance of an object from the sensor. Radiowaves emitted by the sensor bounce back off objects: the greater the time taken for the radiowaves to return, the further away the objects are from the sensor. Modern radar systems use microwaves instead of radiowaves. Radar has three main advantages over other forms of remote sensing: (1) it can 'see' through cloud cover; (2) it generates its own source of electro-magnetic radiation, so it is not dependant on reflected sunlight and can operate at night; and (3) long wavelength (c. 1 m) radar can penetrate dry sand to a depth of about 5 m. There are two major radar applications for expeditions:

- *Rainforests:* previously deprived of remote sensing data because of excessive cloud cover, can now obtain radar images showing terrain, vegetation cover, water bodies, roads and settlements;
- *Deserts:* using long-wavelength radar, images have detected structures buried under sand dunes. Such radar images have proved to be useful aids to mapping underground water supplies and highlighting archaeological sites.

Side-Looking Airborne Radar (SLAR) was developed in the 1960s. The pioneering RADAM-BRASIL survey of 1971-76 revealed the previously un-mapped Amazon Basin. Many governments in the humid tropics (e.g. Indonesia, Malaysia, Nicaragua, Nigeria, and Venezuela) have commissioned radar survey of large regions. Radar sensors have to generate their own electro-magnetic radiation, consequently they are larger than most other remote sensing systems (which passively record solar radiation reflected or emitted by Earth surface features): this delayed radar's deployment on satellites until 1978. Since then, many more radar satellites have been launched and applications developed in monitoring slope stability, subsidence, tectonic and volcanic activity, as well as land cover mapping.

5.6 Recent developments

A recent development related to radar has been Light Detection and Ranging (LiDAR), also known as laser altimetry because it uses a laser beam to measure the elevations of surface features. Airborne LiDAR has been very useful in mapping the heights of trees and generating detailed maps of floodplains, producing contour maps with 15-50 cm intervals, however, it is expensive data and therefore often limited to specific sites.

Integration of remotely sensed data with GIS-based mapping and analysis has become a major growth area, due to five coincidental developments:

- Relatively low-cost Earth observation imagery, with 15 m pixels and good multispectral capabilities, such as Landsat ETM (about US$ 600 per 180 km x 180 km scene) and ASTER (US$ 60 per 60 km x 60 km scene);
- The launch of very high resolution (VHR) satellites, yielding images with 0.5 m – 3 m panchromatic pixels and 3 m – 5 m multi-spectral pixels;
- Hyperspectral satellites, allowing the automatic mapping of Earth surface features, based on computer-generated spectral signatures derived from hundreds of detected wavelengths;
- The ending of the US Government's GPS Selective Availability, improving the accuracy of standard GPS readings from +/- 100 m to +/- 10 m (+/- 3 m with readings averaged over a few minutes);
- Improved integration of GIS and Internet technology should greatly improve the speed and accuracy of fieldwork mapping. The use of data compression techniques, such as the Multi-resolution Seamless Image Database compressor (MrSID), allows rapid Internet transfers of digital imagery.

5.7 Sources of remotely sensed data

5.7.1 Airborne or satellite analogue photography

Airphoto coverage of former British colonies may be held by the Natural Resources Institute (NRI, formerly the ODA) or the Ordnance Survey and three major survey companies: Hunting Surveys, Clyde Surveys, and Aerofilms. For French dependencies or ex-colonies, contact the Phototheque Nationale of the Institute Geographique Nationale. Details of overseas airphoto surveys carried out by the USA can be obtained from the US Geological Survey. To obtain copies of airphotos covering overseas countries, you will almost certainly require an official letter of permission from the relevant land survey department or associated ministry.

Satellite remote sensing began with the USA's CORONA spy satellite missions in the late 1950s. Panchromatic photographs with spatial resolutions of up to 2 m, collected from the KH series of satellites, are available from the US Geological Survey. Photographs from the later Apollo missions can be obtained from NASA's Goddard Space Flight Centre. High quality photographs were obtained using Large Format cameras on the Skylab space station and on the Space Shuttle missions; these can be obtained from the US Geological Survey. 10 m-resolution photographs were taken using Metric Cameras on Space Shuttle missions, these can be obtained from NASA or the German space centre (DLR). Due to the relatively narrow fields of view and the limited numbers of orbits, the chances of getting satellite photos of your study area are slim - but it is well worth enquiring, as their prices are generally low.

5.7.2 Digital images

Scanners that detect variations in visible, infrared and microwave radiation over the Earth's surface can be carried by both aircraft and satellites. Aircraft Multi-spectral data is usually of high spatial resolution (1-10 m) and very high cost. Free, or low cost airborne imagery, derived from test flights, is available, but largely limited to the arid regions of the USA and Europe. The websites of Infoterra and the UK's Natural Environment Research Council (NERC) and the German aerospace agency (DLR) contain useful information on the various types of airborne remote sensing systems.

The main contractors for airborne radar surveys are Aero Service (USA) and Interra Technologies Ltd (Canada). HTS Ltd (UK) (formerly Hunting Technical Services) has also carried out a number of surveys in developing countries. Useful, though limited, coverage of the world was obtained by the US Space Shuttle missions, using the Shuttle Imaging Radar (SIR-A, SIR-B, SIR-C). Although a swath only 50 km wide was viewed during most orbits, many cloud-covered tropical regions were observed for the first time. Another plus point is that the SIR data are *free* from the US National Space Science Data Centre.

A vast array of information on digital remotely sensed images can be found on the Internet: a summary of useful Internet websites is given in the Appendix. The US Geological Survey website is particularly useful for checking global coverage of satellite imagery. It is also worthwhile checking the websites of commercial suppliers of satellite imagery, such as Infoterra (formerly NRSC) and Nigel Press Associates (NPA Group), as they may have archive imagery of your study area. A useful summary of data sources for geoscience fieldwork projects has been produced by Malcolm Whitworth of the School of Earth and Environmental Sciences at Portsmouth University and can be downloaded from *http://web.port.ac.uk/departments/sees/staff/whitworth/dataguide/*

5.7.3 How much will it all cost?

Taken as a single purchase, even Landsat MSS or ETM data (US$ 100 to US$ 500 respectively) can seem to be a luxury item for an expedition; but that price is very reasonable when seen as a cost of *less than one penny per square kilometre*. For comparison, the cost of traditional ground survey techniques to map 1 km^2 has been estimated at £12.50, with only 4 km being mapped in a day (Cooke & Doornkamp 1990). Aerial photography is generally much more expensive per square kilometre, than satellite imagery. Individual airphoto prints tend to cost at least US$50, each print typically covering less than 100 km^2. The market for remotely sensed satellite imagery is very competitive with some dramatic reductions in the price of Landsat data recently and occasional ‘special offers’ from suppliers. As prices can vary so much over just a few weeks, the best approach is to check the websites of major supplies given in the Appendix.

One final tip: discuss your expedition research programme with local natural resource organisations, be they government departments, conservation groups or mining companies – they may give you free access to aerial photography or satellite images and could also provide valuable logistical assistance, while giving you a chance to undertake projects and produce results that will be locally valuable.