Remote sensing at the Warra LTER Site

N.C. Coops
CSIRO Forestry and Forest Products
Private Bag 10
Clayton South, Victoria 3169

Abstract

Long-term ecological research (LTER) sites around the world make extensive use of remote sensing data. Imagery from a range of sensors is often utilised, including data from satellite, airborne and ground-based sensor systems using analogue and digital sensors. The main benefits of incorporating remote sensing into research programs at LTER sites are that the data can be used for inventory, monitoring, change detection and, perhaps most importantly, inter-site comparisons, thereby allowing the different ecological phenomena that occur at each of the LTER sites to be examined. Internationally, a number of remote sensing datasets has been identified as critical to provide sites with information. The majority of these sensors has been used to collect data from the Tasmanian Warra LTER Site. This paper describes the current known holdings of remote sensing data over the Warra region, as well as describing some common processing methodologies for each of the datasets. The current and proposed remote sensing program at the Warra Site is discussed. Ongoing discussion with Warra collaborators using these and other potential datasets is greatly encouraged.

Introduction

The types of remotely sensed imagery applied in forestry and forest ecology can range from analogue aerial photographs to complex airborne and spaceborne digital instruments (Wulder 1998). Interpretation of this forest imagery requires knowledge of the factors affecting the reflectance in the scene, which may be internal or external to the forest stand (Guyot *et al.* 1989). Intrinsic factors that cause changes in the spectral response in forests include canopy geometry, optical properties of the understorey and soil, and the photosynthetic capacity of the leaves (Guyot *et al.* 1989). Extrinsic factors affecting reflectance include the extent of the image area, the orientation and inclination of the ground surface in relation to the location of the sun and remote sensing device, and meteorological conditions. In addition, terrain can also have a significant effect upon stand reflectance (Schaaf *et al.* 1994).

The spatial resolution of remotely sensed data is determined by the sensor's instantaneous field of view which is the area of ground viewed by the sensor at any one time. Conventionally, this quantity is called the pixel size and is analogous to the 'scale' of the image (Woodcock and Strahler 1987). Obviously the resolution capacity of the sensor dictates the spatial variability and the potential amount of forest information extractable from the scene (Wulder 1998). The spectral resolution of remotely sensed data is a measure of the narrowest spectral feature that can be resolved by the sensor. In the past, the spectral resolution of satellite sensors has been very wide, covering large sections of the electromagnetic spectrum in each spectral channel. With the introduction of new technology, there are more instruments, both on satellite and airborne systems, that have much finer spectral resolution, and more distinct spectral channels.

e-mail: nicholas.coops@csiro.au

The Long Term Ecological Research (LTER) Network, in the United States, has made extensive use of remote sensing data (Vande Castle 1998). The LTER network uses data from a variety of satellites, as well as airborne and ground-based sensor systems. For example, photographic remote sensing products (i.e. aerial photographs) are used in the establishment of site locations and monitoring of local vegetation change studies. Imagery from digital sensors is becoming more popular for studies of vegetation change at the individual species and plot scale. Satellite data, in particular the regular acquisition of Landsat Thematic Mapper (TM) sensor imagery, are seen as important sources of unbiased, systematic and comparable data, allowing the USA sites to be placed in a geographic and temporal context (Vande Castle 1998).

The Warra LTER Site is one of four Australian LTER sites (Bradley *et al.* 2000). Warra is situated in southern Tasmania (146° 40′E, 43° 04′S), near the junction of the Huon and Weld Rivers. The site has an elevation range of 37–1260 m and covers an area of 15 900 ha. The region is temperate, and the vegetation is broadleaf forest (mainly *Eucalyptus obliqua*) with some areas of moorland, alpine communities, temperate rainforest, riparian forests, conifer forest and scrubs. The other three sites include the canopy crane research facility in northern Queensland, and the St Marys and Barakula sites in southern Queensland (Bradley *et al.* 2000).

The USA LTER program has specifically developed linkages with agencies and satellite programs to gather imagery over its LTER sites. In Australia, the situation is similar, with ongoing collaborations between the State and federal government agencies coordinating the LTER research programs and organizations such as Forestry Tasmania, the Global Research Network System (GRNS), CSIRO, the Australian Greenhouse Office (AGO) and the National Forest Inventory (NFI) amongst others.

The aim of this paper is to provide a broad coverage of the currently available, remotely sensed datasets at the Warra LTER Site, as well as describing a number of new sensors whose data may hold great potential for ongoing work at Warra. The paper does not aim to provide a comprehensive review of remote sensing systems or detail Warra or global LTER results; rather, its aim is to alert interested readers and researchers to existing and potential remote sensing databases available for analysis and inclusion into ongoing Warra research programs.

General data availability and acquisition

In 1998, scientists associated with the USA LTER network reaffirmed the important role remote sensing had to play in the inventory and monitoring needs of this network (Vande Castle 1998). A range of satellite and airborne imagery was seen as important, including spectral information in the visible, near infrared, mid-infrared and thermal wavelengths (known as optical or passive imagery), as well as imagery from active remote sensing devices such as RADAR and LIDAR. Gosz *et al.* (1989) concluded the main benefits of incorporating remote sensing into USA LTER research was that the data could be used for inventory, monitoring, change detection and, perhaps most importantly, inter-site comparisons allowing the different ecological phenomena that occur at each of the LTER sites to be examined. As a result, within the USA, all LTER sites are included in the NASA global change program. In addition, most sites are sampled as part of the NASA Pathfinder program, where historic and present broadscale remote sensing imagery is acquired for comparison with ground-based measurements.

Remote sensing data availability at Warra

Based on the report by Gosz *et al.* (1989) and Vande Castle (1998), a number of remote sensing sensors were identified as important to provide USA LTER sites with data. In

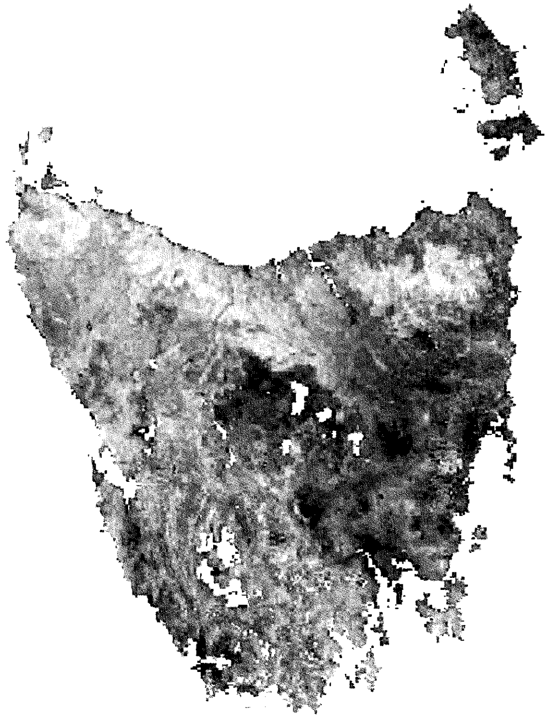

Figure 1. Monthly composite of NDVI scenes over Tasmania using AVHRR 1 km imagery.

most cases, data have been collected over the Warra Site from these sensors as well. These sensors, basic characteristics and imagery holding for the Warra Site, are listed below.

NOAA-AVHRR

The Advanced Very High Resolution Radiometer (AVHRR) was first carried by the USA National Oceanic and Atmospheric Administration (NOAA)'s Polar Orbiting Environmental Satellites in 1978. The AVHRR instrument measures reflectance in the visible, near infrared and thermal regions of the spectrum at a spatial resolution of 1 km and these data are collected by over 200 stations world-wide, principally for meteorological applications (Hastings and Emery 2001). The sensor has a 12-hour repeat cycle, allowing a night and day image to be acquired for the same point on the globe. As interest in regional and global environmental studies has increased, efforts are underway to develop internationally co-operative ventures to collect, routinely process and distribute periodic global full resolution AVHRR data. The image archive (known as 'Pathfinder') accumulated from these sensors over 20 years has become a major resource in global change research as a result of consistent processing algorithms which have recalibrated and renavigated the imagery (Agbu and James 1994). More information on this global project is available at the EROS Data Centre (EDC) website at http://edcwww.cr.usgs.gov/landdaac/1KM/1kmhomepage.html. In addition, a number of groups in Australia are currently processing AVHRR imagery. These include CSIRO, through the Common AVHRR Processing Software (CAPS) (Turner *et al.* 1998), and Environment Australia through its seasonal conditions www. site (http://www.environment.gov.au/psg/erin/land/monitoring/index.html). Figure 1 shows an example of a 1 km NOAA AVHRR NDVI composite. The figure clearly shows the broadscale nature of the AVHRR imagery, with NOAA AVHRR data ideal for covering regional and continental scale changes in vegetation cover, seasonally and annually.

Landsat MSS and TM

Imagery from sensors on the Landsat series of satellites is probably the most important medium resolution dataset used in the international LTER program (Gosz *et al.* 1989). Landsat 1, originally known as the Earth Resources Technology Satellite (ERTS), was launched in July 1972 and ceased to operate in 1978, more than five years after its launch date. By that time, Landsats 2 and 3 had been launched and, between 1972 and 1984, a Landsat was launched roughly every three years. Landsats 1–3 carried the Multispectral Scanner (MSS, Table 1). Landsats 4 and 5 were virtually identical and each carried an MSS sensor and an improved scanner, the Thematic Mapper (TM), which has more bands and finer spatial resolution than the MSS sensor.

Table 1. Specifications of the MSS sensor on board Landsat 1, 2, 3, 4 and 5.

Band number	Spectral range (microns)	Ground resolution (m)
1	.5–.6	79/82
2	.6–.7	79/82
3	.7–.8	79/82
4	.8–1.1	79/82

As the nominal altitude of Landsats 1, 2 and 3 vs 4 and 5 was different, ground spatial resolution varied between satellites.

Table 2. Specifications of the ETM+ sensor on board Landsat 7.

Band number	Spectral range (microns)	Ground resolution (m)
1	.45–.515	30
2	.525–.605	30
3	.63–.690	30
4	.75–.90	30
5	1.55–1.75	30
6	10.40–12.5	60
7	2.09–2.35	30
Pan	.52–.90	15

Table 3. List of Landsat TM and MSS scenes purchased over the WARRA LTER Site.

Date	Sensor
17th October 1981	MSS
9th March 1984	MSS
6th February 1987	MSS
17th February 1991	MSS
6th February 1993	MSS
26th January 1989	TM
12th January 1993	TM
12th February 1995	TM

Landsat 6 was launched in October 1993 but failed to achieve orbit, and Landsat 7 was launched on April 1999, carrying the ETM+ sensor (Table 2), a further improvement on TM, with six visible and near infrared bands, an additional 15 m panchromatic channel, and a 60 m rather than 120 m thermal channel (EROS Data Centre 2001). An example of Landsat TM imagery over the Warra Site is shown in Figure 2. At the Warra LTER Site, eight Landsat MSS and TM images have been obtained from 1981 to 1995. These images are listed in Table 3.

RADAR

Radar (RAdio Detection And Ranging) measures the strength and time that it takes a microwave signal that is emitted by an airborne or spaceborne antenna to be reflected off a distant surface or object. Radar antennas alternately transmit and receive pulses at wavelengths in the range 1 cm to 1 m (corresponding to frequencies of about 300 MHz to 30 GHz) and polarisations (waves polarised in a single vertical or horizontal plane) (Freeman 2000). The size of the radar antenna determines the resolution in the azimuth direction of the image, with the longer antenna resulting in finer spatial resolution. As a result, Synthetic Aperture Radar (SAR) is a technique which synthesises a very long antenna by combining signals received by the radar as it moves along its flight track (Freeman 2000).

Generally, the higher or brighter the backscatter (or response) on an image, the rougher the surface being imaged. As a result, flat surfaces will reflect little or no microwave energy back towards the radar and thus will appear dark in radar images. Vegetation which is usually moderately rough (on the scale of most radar wavelengths) will appear grey in radar images. Surfaces inclined towards the radar will have a stronger backscatter than surfaces which slope away from the radar and will tend to appear brighter in a radar image. Some areas will not be illuminated by radar, such as the back of mountains, which are in shadow, and will appear dark.

RADAR imagery is available both from spaceborne and airborne platforms.

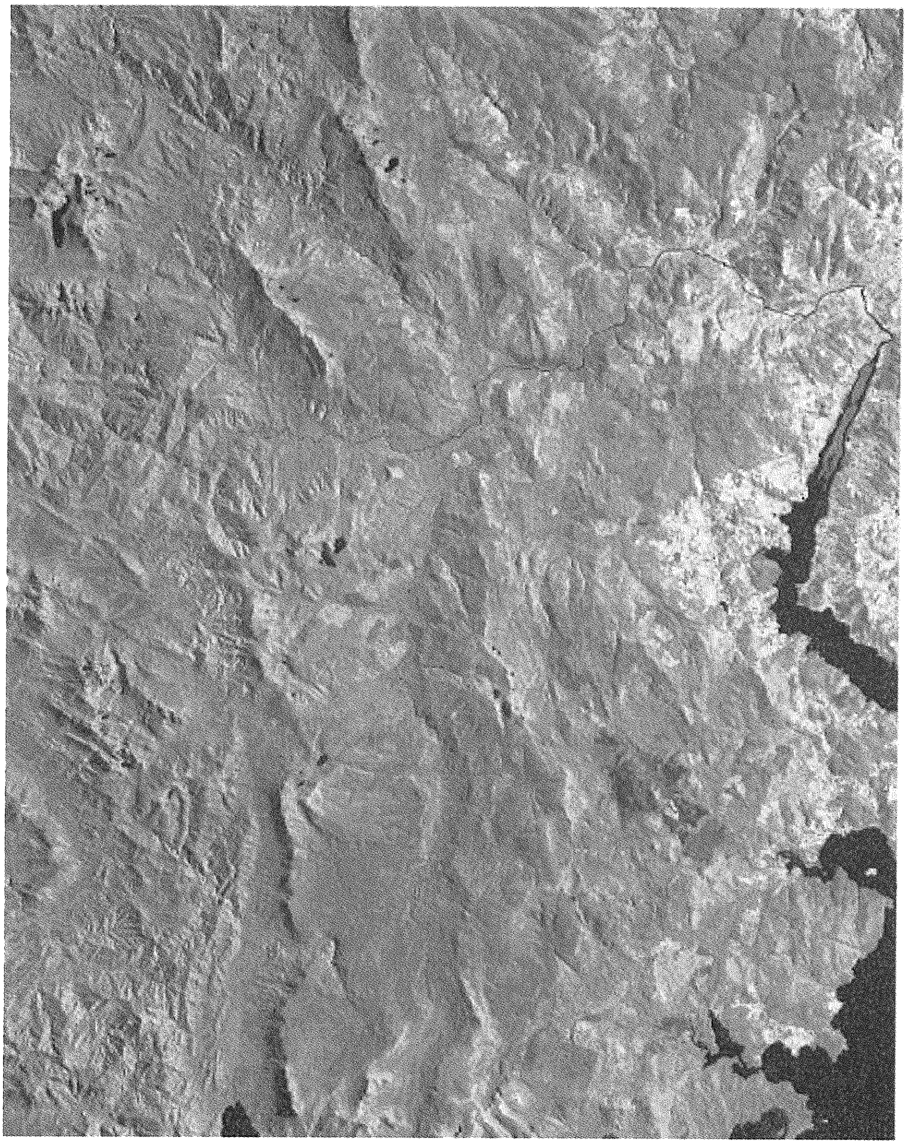

Figure 2. Brightness, greenness and wetness transformation of Landsat TM imagery over the Warra LTER Site. Image covers the extent of the Huon *1:100 000 map sheet.*

Spaceborne RADAR is currently available from the Canadian RADARSAT and Japanese JERS-2 satellite programs and can be obtained over Australian sites from the Australian Centre of Remote Sensing (ACRES). These spaceborne sensors are currently limited to single wavelengths, which can limit their application in forested environments. The most commonly applied airborne RADAR system is the AIRborne Synthetic Aperture Radar (AIRSAR) which is a multi-polarisation, multi-wavelength imaging radar system operating in the C-, L- and P-bands. The corresponding wavelengths of radar are approximately 5.5 cm (C-band), 24 cm (L-band) and 68 cm (P-band). The PacRim2 mission to Australia provided an opportunity to obtain imagery from AIRSAR. The Warra Site was flown on 17th August 2000. A quick-look image of the uncorrected RADAR AIRSAR backscatter is shown in Figure 3.

Figure 3. Quick-look print from the NASA Jet Propulsion Laboratory of the PACRIM-2 AIRSAR campaign over Warra. The transect is uncorrected RADAR backscatter covering a 60 km swath of southern Tasmania.

Digital camera/video imagery

Until recently, the acquisition of very high spatial resolution imagery over forests has been limited to airborne platforms. These include the use of digital videography and digital camera systems. Within Australia, there has been significant development in these types of airborne instruments providing multi-spectral imagery at a variety of spatial scales, from approximately 0.5–5 m (Pickup *et al.* 1995). Digital cameras and videography have the advantage of providing cost effective, digitally processed and recorded data in a number of spectral wave-bands (Coops *et al.* 1998a). However, these data require mosaicing if large areas are to be monitored, and radiometric corrections are required to remove distortions caused by the camera system and reflectance effects (King 1995). As part of a joint project between the National Forest Inventory and East Coast State forest agencies, digital videography was acquired over a number of sites in Australia. The project acquired imagery of Warra at 2 m spatial resolution using the Digital Multi-Spectral Video (DMSV) system built and constructed by SpecTerra Systems Pty Ltd. This system gives four broad band, multi-spectral imagery in the blue, green, red and infrared spectra. The study area was flown as an east-west transect of about 21 km. High spatial resolution orthophotos were also created as part of the project to provide a means to accurately geo-reference DMSV and to assist in locating individual trees during field calibration. Photos were scanned at a resolution of 12 microns, which provided a ground resolution of 0.25 m, and then resampled to 1 m resolution for use as a base image. A subset of the DMSV transect is shown in Figure 4.

In September 1999, the first high spatial resolution commercial satellite, IKONOS, was launched in the USA. The satellite's sensor can acquire 1 m panchromatic and 4 m multi-spectral images from space for any location on Earth. Imagery over Australia can be purchased directly from Space Imaging at www.spaceimaging.com.

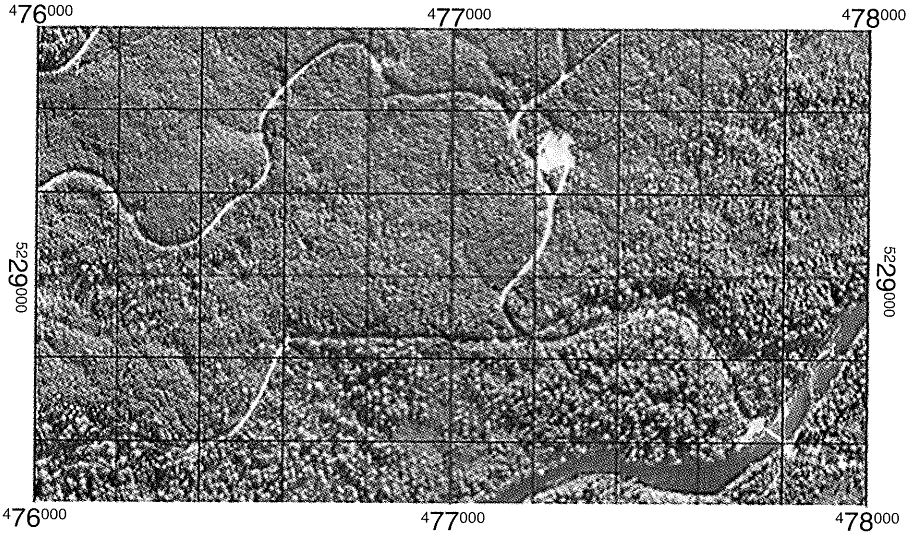

Figure 4. High spatial resolution digital videography of the Warra Site (taken with permission from Preston and Moore 2000).

Aerial photography

To date, the most widely applied remotely sensed dataset at Warra, and throughout Tasmania, is stereoscopic interpretation of aerial photography. Techniques to classify and map the native forests of Tasmania were developed in the late 1940s and a statewide map coverage was achieved using a consistent set of photo-interpretation types and coding standards in 1996 (Stone 1998). This significant achievement is described in detail in Stone (1998). As a result 1:20 000 scale photography is available for the whole public forest estate, allowing a minimum forest patch size of 3 ha to be identified (Stone 1998). The other significant advantage of utilising aerial photography is the historic database available within State agencies, allowing high spatial resolution images of land cover and forest structure change to be assessed over time. Despite the advent of both airborne and spaceborne digital remote sensing instruments, detailed mapping and inventory of Tasmanian forests is still, in most cases, only achievable through aerial photo-interpretation techniques (Stone 1998).

Current research agenda at the Warra LTER Site

Processing of optical data

The interpretation of optical satellite imagery to produce vegetation attributes remains a challenging problem, with multiple factors affecting the signal recorded by the satellite sensor. Processing of imagery often involves two stages: (i) geometric and atmospheric correction and (ii) derivation of spectral indices and classification (Coops *et al.* 1998b). Satellite and airborne images contain a number of geometric distortions, both systematic and random, which can either be removed by the satellite data providers or by the user using common image processing or GIS packages. Atmospheric correction involves the suppression of the effect of the atmospheric scattering on the reflectance values in the image.

Once these distortions have been minimised, there are some clear relationships between the photosynthetic capacity of forest vegetation, regardless of species or age, and the spectral response of the vegetation in selected spectral wavelengths, in particular the visible and near-infrared part of the spectrum. Remote sensing of the near infrared and red wavelengths of the electromagnetic spectrum has a proven capacity for estimating forest leaf area index (LAI) (Peterson and Running 1989; Price and Bausch 1995). In the near infrared region of the spectrum, within-leaf scattering is high and the radiation from the canopy is therefore generally high. However, in the red component of the spectrum, high absorption by pigment results in low radiation reflection. Consequently, LAI is usually positively related to an increase in the difference between near infrared and red radiation (Coops *et al.* 1998b). The Normalized Difference Vegetation Index (NDVI) is a commonly applied ratio of the red and infrared wavelengths and, although a full explanation of the observed correlation between NDVI and canopy properties is yet to be achieved, studies have shown that there is a linear, or near linear, relationship between the fraction of photosynthetically active radiation (*f*PAR) absorbed by vegetation canopies and NDVI (Sellers 1985, 1987; Goward *et al.* 1994). There are several limitations to such an inference but it appears that an estimate of the amount of PAR absorbed can be estimated from NDVI and knowledge of incoming solar radiation (Prince and Goward 1995). Problems can exist at low values of LAI due to exposed ground (van Leeuwen and Huete 1996) and at high values of LAI (in excess of LAIs equal to 4 or 5), where spectral indices saturate (Turner *et al.* 1999). Nevertheless, remote sensing using both simple empirical relationships and more complex algorithms that employ radiation transfer models has the ability to estimate LAI over large domains.

As a result, AVHRR, Landsat and airborne digital camera and videographic data can be transformed to produce predictions of photosynthetic capacity of forest vegetation or LAI. AVHRR NDVI data, due to their daily repeat cycle, can be used to produce temporally dense yet spatially coarse datasets of vegetation functioning, whilst Landsat imagery can be used to extract temporally sparse (16 day repeat cycle) yet spatially detailed predictions of vegetation condition.

Image classification of multi-spectral data is based on the spectral response of different land cover types present in the image by grouping pixels into classes, or categories, based upon distinctive patterns of digital numbers (Wulder 1998). The most commonly applied classification procedure is the maximum likelihood procedure where a statistical decision rule is applied to examine the probability that a pixel belongs to a given class (Lillesand and Kiefer 1987). More recently, contextual classifiers have been developed which allow for the spatial characteristics of the image to be incorporated in the classification, thereby utilising both the spectral and spatial characteristics of a pixel. In contextual classification methods, the classification of an individual pixel is influenced by the characteristics of the surrounding pixels (Gong *et al.* 1992; Wulder 1998).

RADAR modelling

The past decade has seen significant progress in developing approaches to process SAR imagery for a variety of ecological applications. Kasischke *et al.* (1997) provide a detailed review of the application of radar in ecological studies and list a wide range of uses. A key variable which affects radar backscatter is vegetation structure, and the effects of disturbance on vegetation structure (e.g. regeneration and succession) can be apparent on radar imagery. As a result, radar imagery has been extensively applied to gap dynamics in forests caused by falling of trees, logging, windthrow and wildfires. The relationship between pixel size, size and spacing of individual trees, and size and distribution of gaps determines the spatial characteristics (texture) of the radar image. In addition, the effect of moisture, both in the vegetation itself and in the soil, directly affects the backscatter response. Research in the application of radar to biomass estimation has shown the dependence of microwave backscatter on total above-ground biomass, with radar backscatter saturating above certain levels of biomass, dependant on the wavelength and polarisation. The application of AIRSAR imagery at Warra allows the evaluation of the capacity of radar remote sensing to predict vegetation structural attributes over a wide range of forest structure/age classes (caused by the extensive wildfire and harvesting regimes in Warra and surrounds). There is little doubt that a universal SAR biomass equation for continental and global forest is not feasible. However, additional research is being conducted in Australia using datasets and models designed to test the effects of structure on radar backscatter (Imhoff *et al.* 1997). As such, the true capacity and applicability of radar imagery may not be biomass estimation 'directly' but rather to provide a means to stratify forest stands along structural lines to reduce structural variation as a source of error. Once an understanding of the radar response to forest structure has been understood, radar data can be evaluated to estimate woody biomass in the different structural types, including native and plantation species.

High spatial resolution imagery

Results from the NFI-sponsored videography trial have indicated that a number of different forest attributes can be modelled reliably in temperate forests. In particular, tree development index (or growth stage), crown size, and basic land cover attributes associated with logging disturbance can be modelled and spatially extrapolated at very high spatial resolution (Preston and Moore 2000). The use of videography provides a precursor to high spatial resolution, satellite-based monitoring programs, as well as providing high spatial detail to existing programs such as aerial photographic inventory and land cover. Procedures have been developed which allow high spatial resolution imagery, such as videography, to be routinely processed and provided to users in an operative form, in much the same way as satellite remotely sensed data are available today. The continued development of methodologies to process high spatial resolution imagery is likely to increase in the near future as digital cameras become more widely accessible. Much of this activity will take place at Warra due to the availability of high quality, high spatial resolution data.

Linking into research at global LTER sites

Bigfoot

Internationally, a major component of remote sensing research at the LTER sites is involved in validation of the MODIS (the Moderate Resolution Imaging Spectrometer) imagery on-board NASA's Earth Observation System (EOS), Terra. The MODIS instrument was launched in December 1999 and views the entire Earth's surface every one to two days, acquiring data in 36 spectral bands between 405 and 14 385 nm at spatial resolutions from 250 m to 1 km (Running *et al.* 1994). MODIS feeds data into NASA's EOS and produces online data products, including surface reflectance, spectral vegetation indices, land cover, *f*PAR, LAI, net primary productivity (NPP) and land surface temperature (Cohen and Justice 1999).

Within the USA, the 'BigFoot' project explores validation protocols and scaling issues that are important in understanding several of the MODIS land data products, as well as linking into the USA FLUXNET program which has programs concentrating on CO_2, water vapour, and energy exchange using flux tower measurements. As a result, Bigfoot examines over the large LTER sites, 1 km 'footprints' and develops fine grain (25 m resolution) surfaces of land cover, LAI, *f*PAR and NPP. These fine scale surfaces are then aggregated to the 1 km MODIS scale and similarities and differences between these surfaces and the MODIS products assessed. MODIS imagery is now becoming available in Australia and will start to play an increasingly important role in providing remote sensing imagery to Australian scientists. Currently, MODIS derived land products are available from the NASA www. site for the globe at a number of spatial resolutions. ACRES is also providing access to raw MODIS spectral imagery.

Within Australia, similar approaches to the Bigfoot study are currently underway at Injune in Queensland (Lucas and Tickle 1999). These examine the scaling of biophysical parameters derived from satellite and other geographic datasets. The remote sensing datasets currently available at Warra make it an ideal application area for similar projects covering the high biomass, wet temperate forest biomes. Formalising links between Australian LTER sites and the USA LTER sites, through programs such as Bigfoot, would be a significant step in ensuring that the benefits of the Warra LTER Site can be fully exploited.

Ecosystem modelling

Over the last 30 years, considerable progress has been made through the development of general models of ecosystems and in the way that landscapes interact with regional and general circulation models of the atmosphere (Landsberg and Coops 1999). The models track seasonal and interannual patterns of carbon and water vapour exchange at varying spatial and temporal resolutions. Landsberg and Waring (1997) published a stand growth model, based on physiological processes, which incorporates a number of steps and procedures that have allowed considerable simplification relative to extant process-based models. The model, called 3-PG (use of **P**hysiological **P**rinciples in **P**redicting **G**rowth), calculates total carbon fixed by the forest and accounts for the effects of soil drought, atmospheric vapour pressure deficits and stand age and growth. Coops *et al.* (1998c) modified the 3-PG model to produce 3-PGS in which the fraction of photosynthetically active radiation absorbed by the forest canopies (*fPAR*) is estimated from a satellite-derived NDVI from either AVHRR or Landsat MSS Imagery (Coops 1999).

This type of modelling is being undertaken at many LTER sites using a number of models, including BIOME-BGC (Running and Hunt 1993) and PNET (Aber and Federer 1992). A key aim of ongoing work at Warra and the Southern Forests is to continue to evaluate the capacity of remotely sensed data to estimate woody biomass in ecosystems of contrasting structure and biomass density and plantations of hardwood and softwood species. Currently, a range of techniques can be tested at the Warra Site, including the use of existing allometric equations, standard inventory data, and spatially explicit, physiological modelling (using the 3-PG model). The approach will utilise existing geographic and climatic data layers of the region, as well as the AVHRR and Landsat data of the region. If successful, the modelling approach has the potential to provide a new basis of stratification of forestry inventory plots. Current techniques utilise aerial photographic interpretation techniques as well as extrapolating existing plot data which are currently inventoried on Crown Land across a variety of tenures or would require the establishment of new inventories on these areas (primarily private forests, National Parks and wilderness areas).

Additional remote sensing datasets

In addition to the existing remote sensing datasets available at the Warra LTER Site, a number of other remote sensing instruments which can provide imagery are currently operating in Australia but as yet have not been used at Warra.

Hyperspectral

Traditional multi-spectral sensors have measured less than 10 discrete portions of the electromagnetic spectrum. Hyperspectral remote sensing is a technology that allows many more bands to be imaged, thereby facilitating much greater discrimination between features such as geological types, vegetation condition and crop-health evaluations. Currently, two airborne hyperspectral sensors are available in Australia. The Compact Airborne Spectrographic Imager (CASI-2) (Shepard *et al.* 1995) and the HYMAP instrument (Cocks *et al.* 1998) are both capable of acquiring high spatial resolution (0.8–5 m) imagery in 10–256 spectral channels covering the visible, near infrared, and mid-infrared portions of the spectrum.

LIDAR

Lidar (Light Detection and Ranging) technology is a form of active remote sensing in which a laser pulse is emitted from an airborne or spaceborne platform and the return pulse is analysed to provide information from the surface. Currently, terrain LIDAR systems are routinely used in mining and other environmental applications to provide high spatial resolution digital terrain models with very high horizontal and vertical accuracy (Witte *et al.* 2001). LIDAR data acquired over a forested environment can be used to characterise the vertical canopy structure at sample points by recording the complete amplitude of the return signal of the laser pulse between the first and last returns (representing the canopy top and the ground). These measures of the vertical organization of canopy components are critical for modelling factors that relate to biophysical and micrometeorological processes at the atmospheric–vegetation boundary layer (Fournier *et al.* 1995). The availability of canopy LIDAR systems is limited to a single airborne system in the USA (Lefsky *et al.* 1999), with the possibility of a spaceborne platform in the next five years. In Australia, however, encouraging results have been obtained using terrain LIDAR systems to predict tree and stand height (Tickle *et al.* 2001) and these systems offer great potential, especially when combined with optical imagery, to predict canopy height and structure.

Conclusion

Since the establishment of the Warra region as an Australian LTER site, there has been an increased effort to obtain a range of remotely sensed imagery at the site. The remote sensing data that have already been collected have a major role to play in the ongoing research at the site, both with respect to species and structural mapping of the region, as well as facilitating comparisons with other LTER sites in Australia and the world. To date, broad scale, medium scale and fine scale optical remote sensing imagery has been obtained at the site, as well as AIRSAR imagery in the most recent PACRIM mission. This combination of different wavelengths, spectral and spatial resolutions and active and passive systems makes the Warra site an ideal location to carry out remote sensing research for the wet temperate forest biome in Australia.

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