Satellites and Australia

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Introduction

Satellite technologies available in Australia today span a very large range of applications, from telecommunications to global positioning systems and earth observation. Multi-billion dollar investments by various nations and private industry in global positioning systems and earth-observation systems have underpinned the development of agronomic applications, such as 'Precision Agriculture' and satellite-based estimations of feed on offer. Despite this large supply of technologies, the uptake of such remote sensing for pasture management has been minimal due to the difficulty of use of this data by non-experts and the lack of routine accessibility to support day-to-day management decisions.

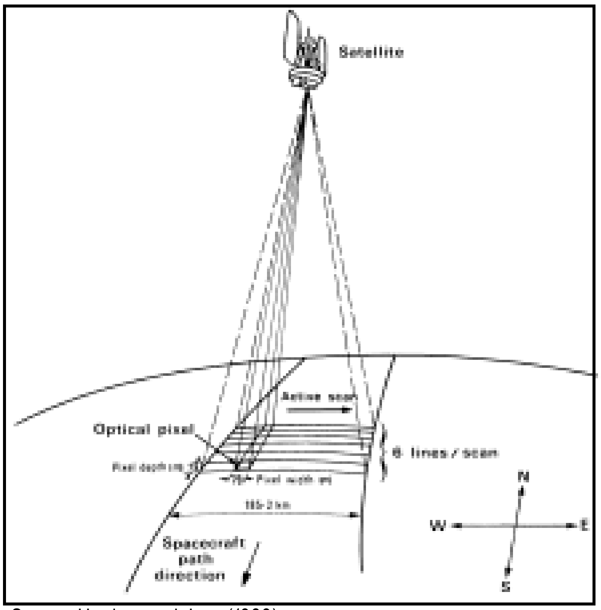
This paper will provide a brief description of the technology of earth observation in Australia, followed by some concrete examples of its use in baseline mapping of the diversity and extent of grasslands for monitoring of pasture condition and estimation of feed quality, in particular.

Basics of the technology

Remote sensing refers to a commonly used 'earth-observing' technique of identifying and measuring the earth's surface characteristics using its reflected or emitted electromagnetic radiation (e.g., light and microwaves) as the carrier of information between the earth's surface and the detection system (e.g., a satellite or aircraft-mounted 'camera' system). The images produced by such sensors can then be processed with specialised mapping software to create digital representations of the distribution and density of different objects (e.g., trees, shrubs, and pastures) across the landscape (for details, see review by Hill, 2003).

Together with traditional ground assessment, remotely sensed data also provides a powerful dataset for historical analysis of the changing condition of grassland ecosystems, since satellite data is available from the late 1970s, when some of the first earth-observing satellites were launched, to the present.

Airborne- and satellite-based sensors with different levels of spatial detail (i.e., ground resolution) and spectral detail ('colour' discrimination) are available in Australia. A relatively new technique used for environmental assessments is called hyperspectral imaging (or imaging spectroscopy). It offers up to 288 spectrally different information layers (bands), which in turn present a higher opportunity to better discriminate among different grassland types or allow for development of quantitative pasture quality measures. Other sensors, called imaging radar systems, map the strength and polarisation characteristics of radar microwaves reflected from the different landscape elements, thus providing valuable information about the size, density, and biomass of forests and grasslands across the terrain.



Source: Harrison and Jupp (1989).

Figure 1. Diagram of a typical earth-observing satellite (Landsat Multispectral Scanner).

The information derived from such mapping systems *per se* is most often only a surrogate for the actual metric of pasture condition or grassland type, and these surrogate measurements must be converted to the actual information required. Its advantage, however, is that it covers 100% of the ground surface and is very precise in a geographical sense, thus reducing extrapolation errors and the costs associated with ground sampling, when it is sensibly combined with point-based ground measurements. This data also allows objective auditing and accurate multi-year change mapping to be done.

Principles of grassland remote sensing

At the canopy scale, grasslands can provide a wide diversity of colour, structure, and composition. From a remote-sensing point of view, the key biophysical features of interest are: (1) height and variation in height, (2) soil coverage, (3) leaf area, (4) leaf orientation or leaf angle distribution, (5) density of reflective or absorptive structures, (6) proportion of senescent or dead material, (7) moisture content, (8) pigmentation, (9) spatial arrangement of structures, and (10) variability of all of the preceding due to species diversity and management. At the paddock scale, the relative mixture of these characteristics is what creates the spatial and spectral variability observed during the mapping and classification process. Thus, traditional applications in remote sensing of grasslands have included the development of baseline maps, where different types of vegetation are drawn across the landscape at various spatial resolutions and with varying levels of classification detail.

Changes in pigmentation among land-cover types have provided the most sensitive and remotely detectable measure of vegetation dynamics. The prominent rise in reflectance of green vegetation between the wavelengths of 680 and 750 nm, commonly termed the 'red edge', is caused mainly by the combination of strong chlorophyll absorption and leaf internal light-scattering properties. This sharp increase in reflectance has enabled the development of 'greenness indices', such as the normalised difference vegetation index (NDVI), which in turn have been used to track changes in canopy cover along the growing season.

Example applications in Australia

Mapping pasture type and condition

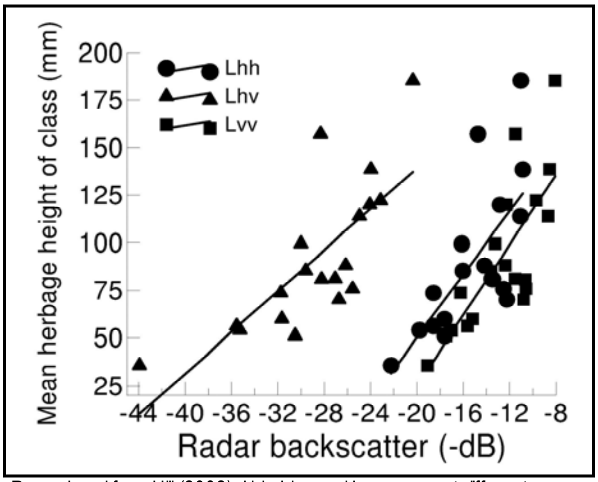
For this application, satellite imagery from the Landsat Thematic Mapper and Multispectral Sensors are primarily used. Such maps have been developed to assist in the application of superphosphate fertiliser to pasture or to describe broad pasture types (Figure 2, left). The method takes advantage of an increased greenness, detectable in the spring and associated with the change from native to semi-improved to fully improved pasture in temperate perennial pasture systems of southeastern Australia. Associated transitions in botanical state are likely to have resulted from the use of sulphur and phosphorus fertilisers, intensive grazing, naturalisation of exotic annual legumes, and establishment of temperate perennial grass pastures. The method has also proven useful in the development of pastoral land-cover classification when the 30-m Landsat data is combined with a time series of 1-km-resolution, advanced very high resolution radiometer (AVHRR) NDVI data (Figure 2, right).

Biomass accumulation

Managed grasslands need to be monitored frequently to manage feed supply, change stock numbers, or introduce supplementary sources of feed. The availability of a time series of satellite images at resolutions of 30 m to 1000 m across more than 20 years has allowed the use of imagery to identify seasonal cycles in vegetation cover. In many cases, good relationships have been established between field biomass measurements and various combinations of individual satellite spectral bands, although some of the derived relationships between the remote sensing surrogate (.e.g., greenness) and biomass tend to be specific for regions and pasture mixtures.

A good example of this application is the Pastures from Space project of the Western Australian Department of Agriculture, CSIRO Livestock Industries, and the Department of Land Administration, which uses 30-m resolution imagery to derive feed on offer (Figure 3) and regular fortnightly satellite information to derive pasture growth rates (Figure 4).

Another remote-sensing technology used for biomass assessment is radar, since the reflections of microwaves produced by such systems are sensitive to variations in canopy moisture content and structure. The strength of the return signal has commonly shown good positive correlations with crop biomass, and the relationships between sward height and radar backscatter for diverse pastures (Figure 5) suggest that there is potential for routine biomass estimation in pastures using such technologies in the future.

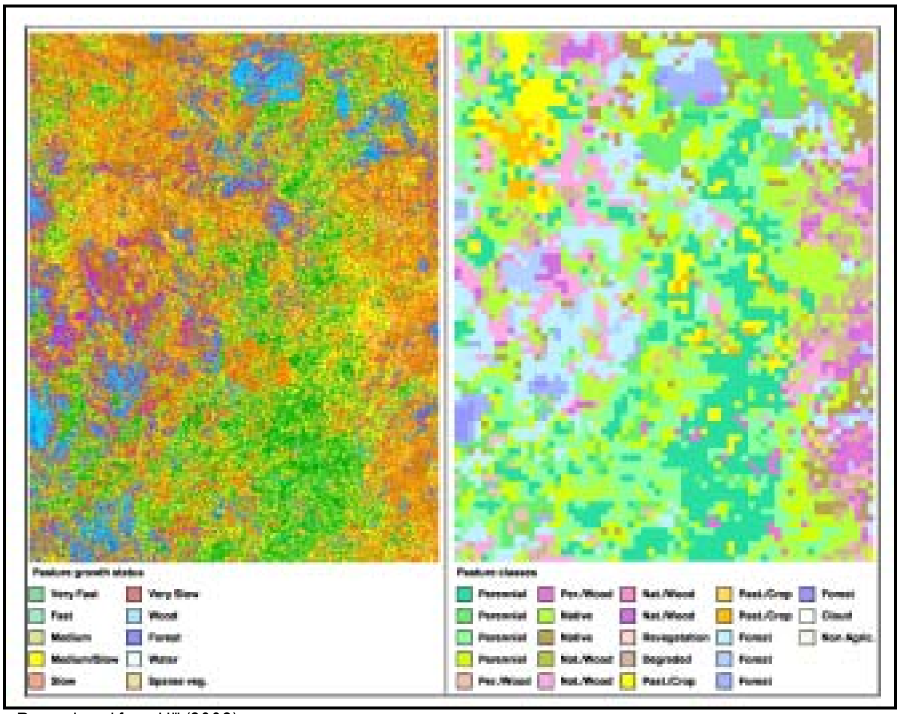


Reproduced from Hill (2002). Lhh, Lhv, and Lvv represent different microwave polarisation angles for transmitted and received L-band radar waves.

Figure 5. Relationships between L-band radar backscatter and height of diverse pasture classes at Armidale, New South Wales.

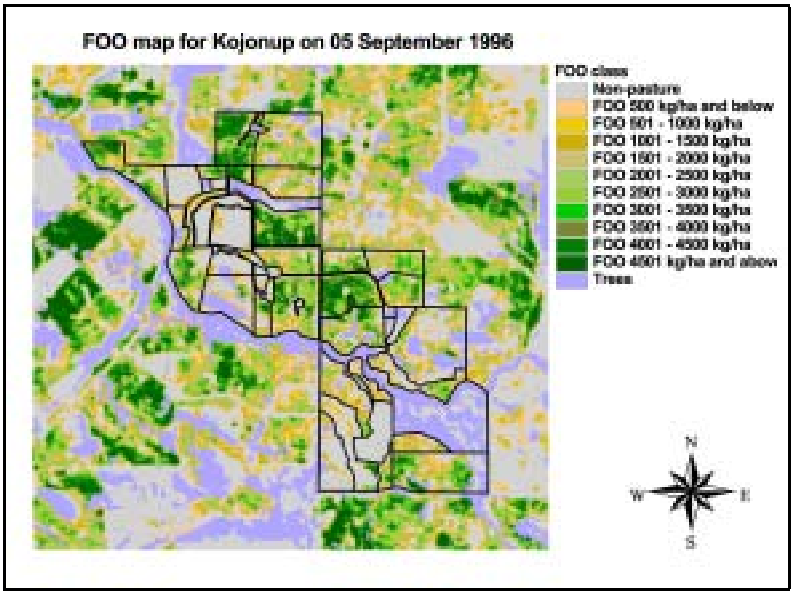
Pasture quality and chemical composition

A fundamental priority in managed grasslands is the maintenance or improvement of the nutritional status of the feed resource. The analysis of feed quality with near-infrared reflectance spectroscopy is commonplace; however, detailed chemistry of moist plant tissues tends to be more difficult to measure. In the visible spectrum (400 to 700 nm), leaf reflectance is quite low (< 10%), due to the absorption of photons by water and a range of photosynthetic pigments (mainly chlorophylls and carotenoids). At wavelengths above 700 nm, the plant constituents that determine forage quality—nitrogen, water, cellulose, and lignin—are also responsible for significant absorption in the spectra of forage plants.



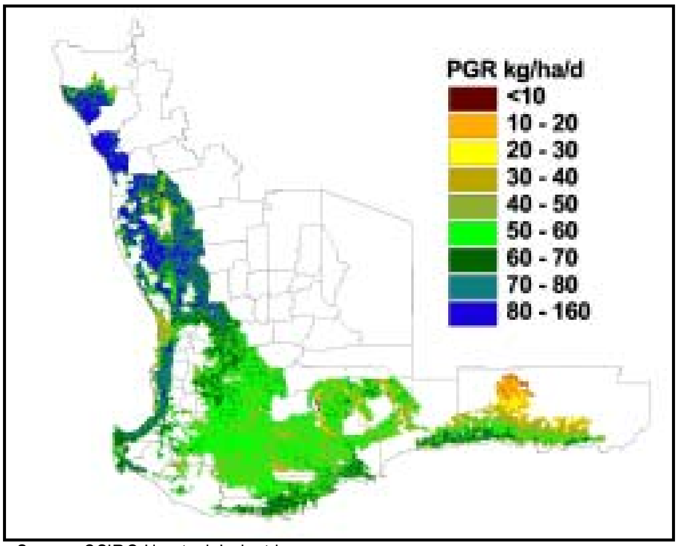
Reproduced from Hill (2002).

Figure 2. ***Left:*** **Pasture growth status map showing broad pasture types.** ***Right:*** **Pastoral land-cover map for a corresponding area.**



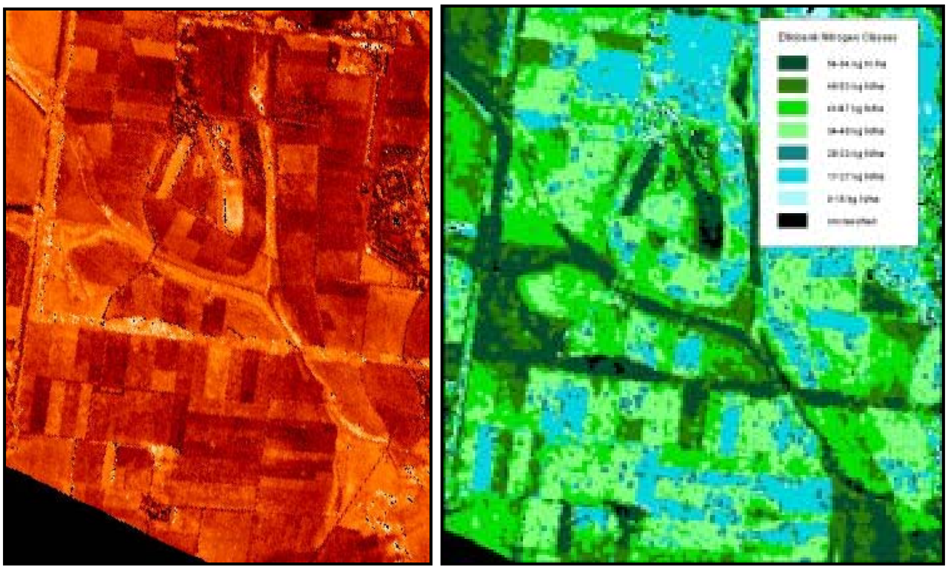
Source: CSIRO Livestock Industries.

Figure 3. Map showing feed on offer for a property near Kojonup in southwest Western Australia, derived from empirical relationships between Landsat Thematic Mapper NDVI and measured pasture biomass.



Source: CSIRO Livestock Industries.

Figure 4. Pasture growth rate map for southwest Western Australia derived from US National Oceanic and Atmospheric Administration AVHRR NDVI time-series data and growth models.



Source: Thulin *et al.* (2002).

Figure 6. *Left:* Red-edge position image for Ellinbank, Victoria. *Right:* Seven-class nitrogen image based upon the empirical relationship between red-edge position and total pasture nitrogen mass.

While the characteristic green canopy reflectance is detectable from older satellite sensors, a number of important features of leaf reflectance, such as the levels of primary and accessory pigments, moisture, and lignin content, cannot be measured with such 'broad-band' sensors and can only be detected in measurements made with higher spectral resolution (hyperspectral) satellite sensors. Since the end of 2001, such technology has been available from satellites and provides an opportunity to develop measures of the spatial variability in pasture composition and nutritional quality across the landscape.

An example of this is the use of the established relationship between the wavelength of the red-edge inflection point (Figure 6, left) and the chlorophyll content of the observed plant material to develop an indicator of nitrogen mass in dairy pastures at Ellinbank, Victoria (Figure 6, right). There is a strong correlation between chlorophyll content and nitrogen content of pasture. However, the real goal is to use spectral absorption features to directly estimate pasture nitrogen concentration.

Rapid delivery of relevant information

In addition to the ability of satellite-derived information to provide accurate and realistic estimates of pasture growth rates, composition of grasslands, and aspects of their chemical status, the effective delivery of such information in a timely and understandable manner is also critical, in our view, to the adoption of satellite-derived information products by the pastoral, grazing, and ecological communities.

The Pastures from Space project in Western Australia is a good example of the levels of adoption and utility of this type of information by pastoralists when it is delivered via a simple-to-use web-based interface at regular intervals and at a sufficient level of accuracy for use in day-to-day, farm-level decision-making.

A second example, using similar concepts but designed to provide faster turnaround of satellite-derived information (four times every 24 hours) is the Sentinel Hotpots system used for bushfire identification and tracking. This system has not only proved a strong demand for such timely information by fire and emergency management agencies around heavily populated areas of southeastern Australia, but is also used by such agencies as the Cape York Development Authority for routine locating and tracking of remote-location grassland fires in tropical savannas and woodlands.

Current R&D and future sensor systems

In recent years, web-based delivery techniques and advanced satellite sensor systems (e.g., hyperspectral and radar) have created a number of new opportunities for research and development of increasingly more-sophisticated information products. Research is currently under way to derive better information on forage chemistry from hyperspectral sensors and better estimates of biomass levels from radar imagery.

Key to the success of this research is the future launch of satellite systems that are able to routinely provide such advanced imagery, repeatedly covering large areas of Australia. Both NASA and the European Space Agency have launched high-quality earth-observing systems in the last 2 years on board the Terra, Aqua, and Envisat satellite platforms. These earth-observing systems include the Moderate Resolution Imaging Spectroradiometer (MODIS), the Multi-angle Imaging Spectroradiometer (MISR), and the Medium Resolution Imaging Spectrometer (MERIS), all of which have much better calibration stability and are able to discern many more spectral features of vegetation than previous satellites could do. In addition, these platforms pass over any point in Australia nearly every day, thus providing the opportunity to monitor changes in cover and chemical composition of grasslands and pastures at resolutions of up to 250 m. Many remote-sensing research groups at universities and research institutions around Australia are currently developing new ways of using such regular information and of delivering it to the practical user community.

References

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