Australian Government
Geoscience Australia

AUSGEO news
ISSUE 92 Dec 2008

Dynamic land cover mapping from space

Baseline information for environmental monitoring.

Leo Lymburner, Fuqin Li, Peter Tan, Norman Mueller and Shanti Reddy

Geoscience Australia currently uses Earth observation satellites to capture environmental information over the entire Australian continent. The satellites used, including Landsat, the Advanced Land Observing System, and Resourcesat-1, are operated by the United States, Japan and India respectively. Geoscience Australia now holds an archive of satellite observations, over the last 30 years, which supports several nationally significant environmental initiatives. These include the National Carbon Accounting System for the federal Department of Climate Change and the Statewide Landcover and Trees Study (SLATS) by the Queensland Department of Natural Resources and Water.

Traditionally, Geoscience Australia receives raw telemetry data from satellites, archives the raw data on computer tapes and processes selected images on-demand. These images cannot be directly compared over time because the effects of the atmosphere and the sun illumination angle differ between images. Although this mode of operation satisfied expert users of remotely sensed imagery, it is now apparent that the changing needs of government can be more effectively satisfied by further processing of the data. This would require a single calibrated measure of the reflectance of the Earth's surface over the last three decades. Early trials indicate that this would be very useful information for tackling national problems such as water management, environmental responses to climate change, as well as provide data for national environment reporting.

Under this new approach, remote sensing images are firstly converted to measures of surface reflectance. Analysis of the changes in surface reflectance over time yields a number of useful biophysical parameters (or land cover features such as water and vegetation). These are statistics which capture the patterns of change or biophysical dynamics of the landscape, and ultimately allow the cover of the land to be mapped, classified and studied as a dynamic system.

In early 2008, Geoscience Australia initiated a pilot project to explore this new approach and the initial results from the pilot study are described below. Figure 1 outlines the methodology being developed to produce land cover information.

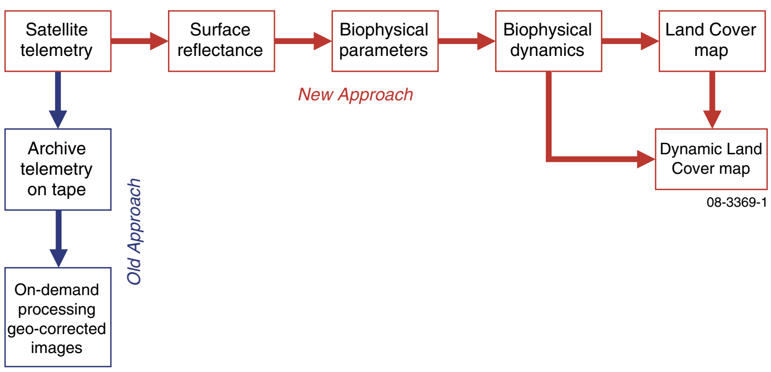

Figure 1. Proposed methodology for dynamic land cover mapping.

Surface reflectance

The radiance values recorded by the sensors onboard Earth orbiting satellites are affected by the atmosphere, solar incidence and direction, as well as sensor view angles at the time of the satellite overpass. Therefore it is necessary to correct for atmospheric, radiometric and view angle effects and derive calibrated surface reflectance values which can stand as quantitative, absolute measures of the land-surface. In the past, many empirical, data dependent and also exploratory methods have been adopted to derive normalised surface reflectance values. Simple transformations such as the Normalised

Difference Vegetation Index (NDVI) have sometimes proved effective in standardising observations to a point where true underlying changes can be sensed. However, these methods are very hard to validate and are not consistent between different sensor systems and surface environment conditions.

Geoscience Australia has developed a physically-based robust algorithm to derive surface reflectance data using MODTRAN ™ radiative transfer model with necessary input data (such as water vapour, aerosols and ozone) to correct atmospheric effects. It also uses observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the TERRA and AQUA satellites to infer the Bidirectional Reflectance Distribution Function (BRDF) which describes illumination and viewing angle effects. Eleven cloud-free Landsat scenes acquired in 2004 over the Gwydir River catchment in northern NSW have been processed to produce reflectance data. Furthermore, data from one 2008 scene has been validated against field measurements (figure 2). Comparison with reflectance estimates from the MODIS sensor also indicate that the method is reliable, robust and produces consistent quality surface reflectance data.

Derivation of biophysical parameters

Use of time-series data, rather than individual images from a single point in time, is a major advance on previous methodologies and is fundamental to a rigorous and repeatable approach to land observation using satellites. For the pilot study, the eleven cloud-free Landsat scenes over the Gwydir River catchment acquired in 2004 were processed to give a short time-series, or 'stack', of reflectance data.

When assessing a stack of Landsat or MODIS surface reflectance data for a particular region it is necessary to be able to extract summary information so that the data can be clustered, regionalised and classified. Such summary techniques need to be robust because the ultimate goal will be to apply them to any time-series without any prior knowledge or manual input. The temporal resolution and duration of the time-series must therefore be considered. The list below indicates some of the statistics that can be calculated for any stack of satellite scenes which are used to provide the summary statistics:

- maximum value in a band for that pixel from any scene
- minimum value in a band for that pixel from any scene
- mean and variance value of that band for that pixel for all scenes
- ratio (maximum/minimum)
- timing of the maximum (Epoch during which the maximum value of that band occurred)
- rate of change (linearly or exponentially) from the start to the end of a time series
- difference between the start and the end of a time series
- number of observations above or below a threshold.

If the data covers multiple years, then each of the statistics can be calculated for each year and averaged (for example, average annual maximum). These statistics, whilst being quite basic from a mathematical point of view, account for noise commonly found in remote sensing images. Consequently they are valuable as inputs to appropriate machine learning algorithms, and such analyses

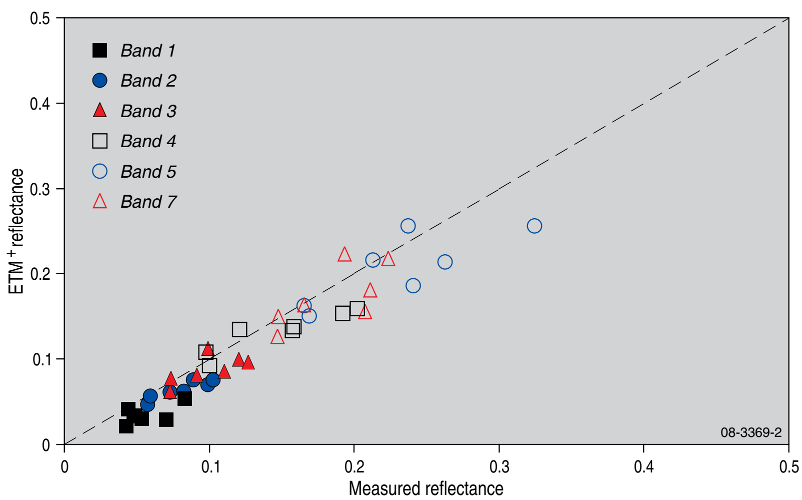

Figure 2. Comparison of Landsat-derived surface reflectance values with field measurements obtained in June 2008, Gwydir River catchment. Reflectance is measured for wavelength band for each pixel.

are capable of providing insight into system behaviour. This point is illustrated in figure 3, which shows a water body map of the Gwydir River catchment generated by aggregating and classifying minimum reflectance values in Landsat Band 5 from the 2004 data stack. Statistics can also be taken on derived land surface measures, for example, on fractional cover or on fractional cover proxies such as vegetation indices and bare soil indices. During the pilot study biophysical parameters at sub-pixel level – that is fractions of soil, vegetation, and non-photosynthetic vegetation (dry grass) – were derived within a 30 metre by 30 metre pixel area using linear spectral unmixing algorithms.

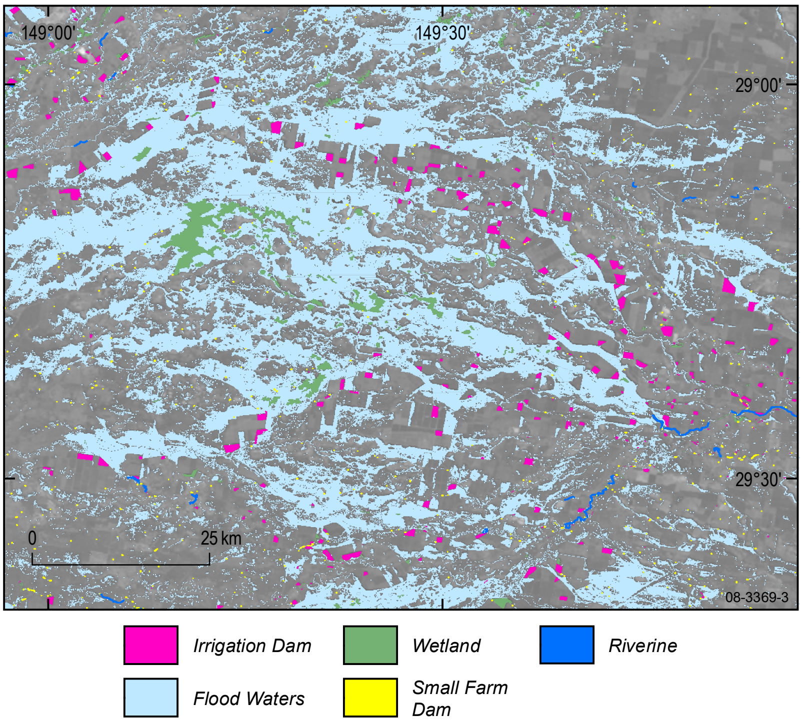

Figure 3. Water body map of Gwydir River catchment generated by aggregating and classifying minimum reflectance values in Band 5 from a stack of cloud-free Landsat images acquired in 2004.

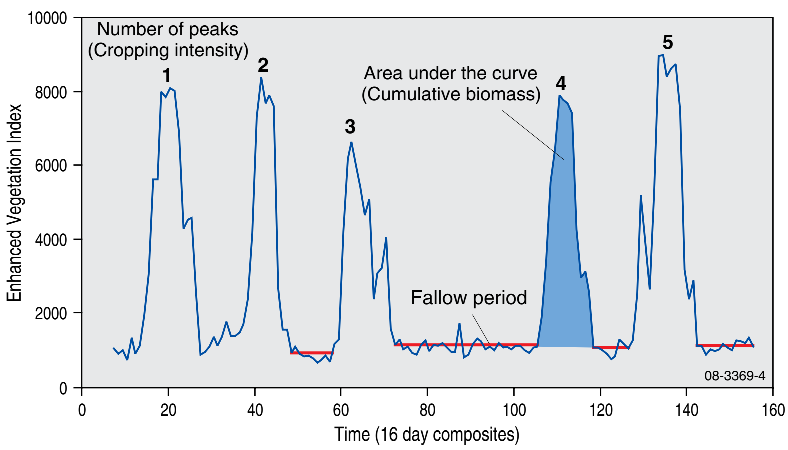

Figure 4. Land use information extracted from tailored time-series analysis of six years of MODIS Enhanced Vegetation Index data.

Extracting biophysical dynamics

Land cover types have characteristic behaviour over time, and time-series data can therefore be interpreted in very specific and targeted ways to infer system dynamics. The study has identified a generic strategy for analysis of tailored remote sensing time-series imagery:

- a time series can be divided into a sequence of sub-time series with shorter length
- characteristics of a time series can be represented by a set of generic statistics extracted from these sub-time series
- a machine learning algorithm, or a more sophisticated statistical method with these generic statistics as input variables, can be used to target specific problems.

Under this strategy, specific remote sensing problems are addressed in two stages. Firstly, a set of statistics are extracted from several shorter sub-sets of the original time series. These statistics are generic, independent of model assumptions and require no input parameters or prior knowledge. In the second stage, application specialists with expert knowledge use these coefficients as input data for more sophisticated interpretation, ultimately producing higher level information products.

As an example, time-series analysis tools were developed to quantify cropping practices. The phenology (or changes over time) of cropped areas is determined by a combination of human activity and natural rainfall variability.

The green fractional cover rises sharply as the crop matures, remains high for a time, before a sharp drop in green fractional cover after the crop is harvested. An interval of zero green cover which follows corresponds to the fallow period. Time-series analysis of the cropping phenology can identify a range of features (see figure 4) including:

- the number of cropping cycles within a year
- the number and cumulative time of fallow periods
- the timing of crop cycles (whether winter or summer crops)
- crop green biomass (estimated by integrating the area under the curve of a crop cycle)
- inter-annual changes in crop green biomass.

Dynamic land cover mapping

The major aim of the pilot study was to develop a method for consistent, repeatable, monitoring of the land cover and this was achieved by classifying the biophysical parameters and time-series coefficients discussed above. This is done within an object-oriented image processing environment which allows users to define a set of rules, spatial attributes of objects, and ultimately a classification. A land cover map shown in figure 5 has been generated by cluster analysis of the time-series coefficients extracted from six years of MODIS Enhanced Vegetation Index data. For this purpose the International Standards Organization (ISO) land cover classification scheme was adopted to produce a consistent quality land cover map across jurisdictional boundaries. Geoscience Australia staff are currently finalising methods to produce land cover maps covering the whole country using MODIS time series data on a fortnightly basis. The Geoscience Australia staff have also demonstrated methods to integrate higher spatial resolution Landsat data with MODIS time-series data to produce a detailed scale ISO land cover classification.

The concept of dynamic land cover mapping and the initial results from this pilot project have been well received during presentations to key Australian Government agencies. The methodology is now being extended to other bioregions to ensure it can be repeated in the full range of Australian environments. The proposed approach promises consistent quality and long term baseline information to support new environmental initiatives at the national level.

The surface reflectance measurements based on Landsat imagery are expected to be of great value to a wide range of ecosystem scientists and this research will be continued under funding provided through the National Collaborative Research Infrastructure Strategy - Terrestrial Ecosystem Research Network (NCRIS-TERN).

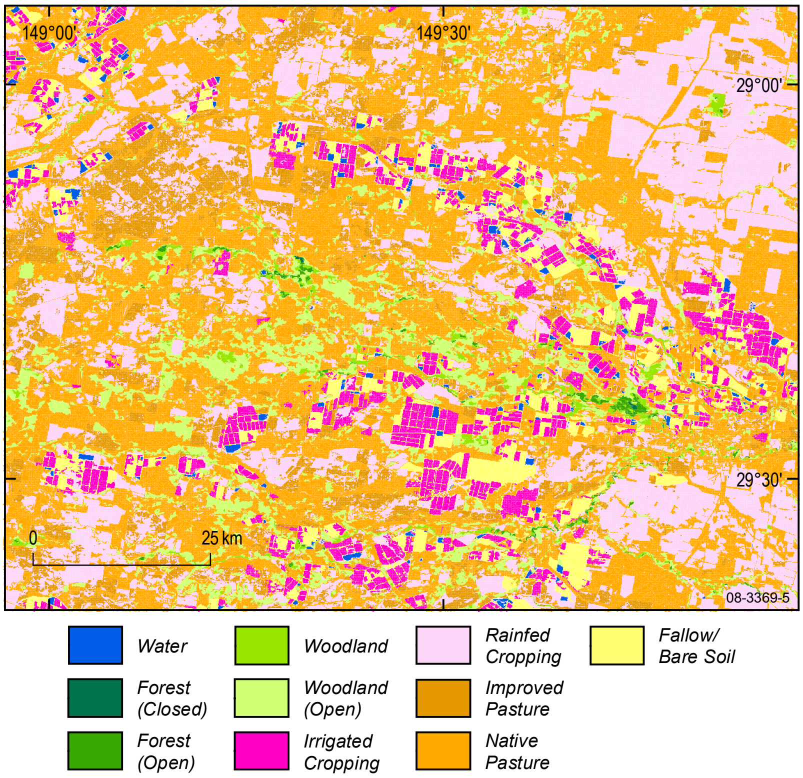

Figure 5. Land cover map of Gwydir River catchment derived from time-series analysis of six years of MODIS Enhanced Vegetation Index data.

For more information

phone Shanti Reddy on +61 2 6249 9647
email shanti.reddy@ga.gov.au