Sub-hectare Land Cover Monitoring; Developing a National Scale Time-Series Program

Dr Gary Richards, Manager and Principal Scientist, National Carbon Accounting System, GPO Box 621, Canberra City ACT 2601, gary.richards@greenhouse.gov.au .

Suzanne Furby, CSIRO Mathematical and Information Sciences, Private Bag 5, Wembley WA 6913, suzanne.furby@csiro.au .

Abstract

Fundamental to accounting for carbon change in forestry and agriculture is an understanding of the change in land cover to detect afforestation, reforestation and deforestation events. The impact of an event associated with land cover change may continue over many years and vary with time since the event took place. It is, therefore, necessary to be able to monitor change in land cover over long timeframes. As there is no other national data source available to describe the time and location of change events, the AGO initiated a multi-temporal land cover change analysis which draws on the archive of relevant satellite data available since 1972.

In the development of a national program involving eleven continental coverages of high resolution Landsat data between 1972 and 2000, the National Carbon Accounting System heavily utilised Australia's private sector. The coupling of the production capacity of Australia's private sector remote sensing industry with the world class research of CSIRO, has provided Australia with an unparalleled data resource suitable for a range of natural resource management applications.

The timely and cost-effective delivery of the program has opened the way for national scale, sub-hectare resolution remote sensing for environmental monitoring.

Introduction

When the Commonwealth Government commenced the development of the National Carbon Accounting System (NCAS) in 1998 as "*a consolidated package to provide the comprehensive framework and scientific services necessary to account for Australia's emissions reduction and sink enhancement programs*" the foundation for one of the world's largest ever environmental remote sensing programs was laid.

Article 4.1(1) of the United Nations Framework Convention on Climate Change (UNFCCC) commits Australia to produce an annual inventory of national greenhouse gas emissions according to the Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. This rule set has been adopted as the basis for reporting under the Kyoto Protocol.

The inventory reports human-induced greenhouse gas emissions by sources and removals by sinks, not controlled by the Montreal Protocol, in six sectors: Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, Land Use Change and Forestry. Reducing the levels of uncertainty previously associated with estimates of Land Use Change emissions is essential as they are a significant component of Australia's greenhouse gas emissions profile.

Fundamental to accounting for carbon change in forestry and agriculture is an understanding of the change in land cover to detect afforestation, reforestation and deforestation (land use change) events. The impact of an event associated with land cover change may continue over many years and vary with time since the event took place. It is, therefore, necessary to monitor change in land cover over extended periods of time. To be considered in the accounting framework, the land cover change also must be shown to be directly human induced, that is, a deliberate, not an indirect natural event.

As there is no other data source available to describe the time and location of change events, the AGO initiated a multi-temporal land cover change analysis which draws on the archive of relevant satellite data available since 1972.

The need to consider land use change as a time continuum, and for the ongoing tracking of any land unit drawn into the accounting framework, demanded a time-series consistency in the treatment of land units, both spatially and through time. As a land unit must be tracked at a maximum area of one hectare, there is a requirement for a fine resolution (sub-hectare) land cover change monitoring capability.

Technical Development

The general policy specifications outlined above provided some clear direction for the attributes of the technical approach. The first was that only the Landsat data series met all criteria of providing a historical archive, sub-hectare resolution and consistent time-series treatment. The definition of the task also determined the temporal sequence of images required, leading to eleven coverages from 1972 to 2000 with the highest temporal resolution around the 1990 (UNFCCC) baseline year.

With the data source established, several subsequent tasks were needed prior to the initiation of the program. These ranged from checks of image availability and quality and expert workshops on detailed methods and known limitations to rigorous pilot testing. From an operational perspective, consideration was also given to the logistical implications of requiring eleven continental coverages to be analysed for change, in time-series, in just over two years.

Consistent with Commonwealth Government industry development initiatives, a decision to train and develop Australian capability was taken. This allowed for the pilot testing of the intended method to also include an industry training initiative.

An initial tender was released to establish a technical management group for the development of methodology. The tender was won by a consortium led by RMIT and CSIRO and included input from the Bureau of Rural Sciences, Department of Natural Resources Queensland, Department of Natural Resources and Environment Victoria and Geoimage Pty Ltd.   This group proposed a preliminary method, based on CSIRO research, which was the subject of a national expert workshop. A two-stage program of pilot testing and training was suggested to address the many issues that needed to be resolved prior to program implementation.

Parallel to the technical evolution of the method, CSIRO developed training and implementation manuals to ensure that there was complete consistency in the application of the specification by all service providers. A comprehensive multi-stage quality assurance process was applied centrally in order to ensure both the quality and consistency of products from the various service providers.

Technical Specifications

The basis of the selected method for the program was the multi-temporal Conditional Probability Network (CPN) approach developed by CSIRO to provide a clearly resolved status of forest or non-forest for a unit of land. This method provided the necessary capability to track individual land units as they are progressively included in the accounting framework. The CPN allowed for treatment of the eleven continental coverages as a time-series, rather than as a series of ten paired differences. This was of key importance to meeting the policy prescriptions.

Fundamental to any change detection study is the co-registration of the multi-temporal image sequence. The geographic registration of images against a consistent base was achieved by the registration of a time series of images against a national (mosaic) base. A continental mosaic of Landsat ETM^+ data for late 1999-early 2000 was developed for this purpose. The mosaic was also used as the calibration base, with the data from the time series calibrated to this base to provide radiometric consistency through time.

The continental mosaic base was compiled using the PCI Orthoengine Software providing for both orbital and terrain corrections with full block adjustment. Correction for sun-angle was achieved using the Bi-directional Reflectance Distribution Function (BRDF) approach developed by the Queensland Department of Natural Resources and Mines.

Air photographs were interpreted to provide training sites for the selection of indices (band weightings) that discriminate between forest and non-forest cover for each of a series of forest, soil type and terrain strata. Thresholds were then applied to the indices to map the probability of being in a forest or non-forest state based on three potential cover classes; forest, non-forest and uncertain for each of the eleven coverages. The CPN software was then applied to resolve areas of uncertain status by reference to the previous and subsequent probability maps.

An attribution mask was then derived to determine which changes (moving between forest and non-forest) met the test of being directly human induced land use change. This was used to separate out features such as salinisation and dieback from directly human induced land use change.

Program Implementation

The program implementation was effectively broken into six stages; scene selection, formation of the Year 2000 mosaic base image, geographic registration and radiometric calibration, mosaicing of individual path/row data into the 1:1,000,000 map tiles of Australia, land cover change thresholding and attribution to form land use change maps. Separate tender processes were applied for each of these stages. This staged approach was arrived at after the experiences of the pilot testing.

During the pilot testing each contractor applied the full processing sequence, from image registration through to change thresholding, to an assigned region. This formed an inadequate basis for quality assurance as substantial rework is required if errors made in the early stages of the process are not detected until the final stage. Instead, linked multi-stage processing and quality assurance programs were developed. The eventual program and quality assurance stages are shown in Figure 1. With the program broken into six major phases a far stronger central role was developed for both quality assurance and work program monitoring.

With the service provider capacity developed through the industry training it was possible to operate the program, and each of its stages, on a competitive basis. The competition for packages of work within each processing stage led to both keen pricing and rapid turnaround by contractors.

Despite the extensive pilot testing, involving the processing of some 160 Landsat scenes, there were logistical difficulties in initiating the overall work program involving some 3,300 scenes. Establishing price benchmarks for the full operational program was also initially difficult as considerable savings on those established during the pilot testing were achieved.

Output Products

The principal output from a greenhouse gas emissions monitoring perspective is the time-series mapping of land use change. However, there is clearly a broader range of potential applications of the data in natural resource management. To this end, the Australian Greenhouse Office has negotiated access agreements for cost of transfer access to the data products by other Commonwealth agencies and State and Territory Governments. Geoscience Australia will also distribute products commercially through its normal distribution channels.

Use of Results

The principal use of the data by the Australian Greenhouse Office has been incorporation into the *FullCAM* model of the National Carbon Accounting System. *FullCAM* is an integrated carbon accounting model for agriculture and forestry activities. *FullCAM* uses a mix of spatial (including the remote sensing) and tabular data to derive emissions estimates from soil, litter and biomass carbon pools.

The wider availability of the data for a broad range of natural resource management issues is likely to evolve over time. To date, the focus has been on developing the data and providing mechanisms for distribution. Wider promotion for awareness and broader potential applications will also develop over time.

Conclusions

In a space of around three years the remote sensing program of the Australian Greenhouse Office has brought about fundamental changes in Australia's remote sensing capability and perception. These changes have been in the broadening of the understanding of the scale of programs that can be implemented and of the role of the private sector in major Government remote sensing activities. Previously, cost was a considerable barrier to large scale programs, but it has now been shown that the use of outsourcing and other production efficiency factors (methods and software) have a significant impact on cost. The unit costs of the Australian Greenhouse Office programs are around one-fifth of comparable benchmarks reviewed at the program outset.

With the successful completion of this program it is now a realistic expectation of Government that sub-hectare remote sensing can be used for routine environmental monitoring. The reduced cost and increased Government confidence in program delivery and outputs should provide for a solid advancement of the role of remote sensing in natural resource management and of the role of the private sector in Government remote sensing programs.

Details on the National Carbon Accounting System including the specifications for the remote sensing program can be found at http://www.greenhouse.gov.au .

Figure 1: Stages in the National Carbon Accounting System Land Cover Change Program