LONG TERM EARTH OBSERVATION DATA FOR FOREST CARBON TRACKING: AUSTRALIA'S EXPERIENCE AND GLOBAL DEVELOPMENTS

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Abstract - The Australian Government's National Carbon Accounting System (NCAS) was developed to report land sector greenhouse gas emissions to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. NCAS uses a national wall-to-wall time-series of Landsat (optical) satellite data from 1972 to 2010. Independent verification has shown that the analysis can generate a stable and robust time-series analysis of forest cover change.

Similar systems also using wall-to-wall time-series mid-resolution remotely sensed data analyses are now being considered for monitoring, reporting and verification (MRV) for REDD+. Many of these systems are adding use of radar satellite data to the optical time-series.

Improving both the coordination and accessibility of satellite and ground observations, and the transfer of technologies will be required to support a worldwide network of national MRV systems. Additional technical challenges are around the interoperability of optical and radar data, and the integration of systematic ground measurements (inventory) and the remotely sensed data.

Keywords: NCAS, REDD+, remote sensing, deforestation, greenhouse gas emissions and removals, GEO GFOI, MRV.

1. Introduction

The Kyoto Protocol rules provide that in countries where the emissions from deforestation are greater than the emissions removed (carbon sequestered) by forests, those countries can include emissions from deforestation in their 1990 baseline. The baseline is used in the assigned amount calculation that sets the emissions target for the commitment period 2008-2012. This is set out in the 2nd sentence of Article 3.7 of the Kyoto Protocol.

Countries reporting under the Kyoto Protocol are required to account for emissions and removals from afforestation, reforestation and deforestation over the commitment period of 2008 to 2012. Including the emissions from deforestation in the 1990 baseline effectively allows countries to count reductions in deforestation against their Kyoto Protocol emissions reductions target. The methods developed by countries to report these reduced deforestation emissions under the Kyoto Protocol can provide lessons for countries implementing monitoring, reporting and verification (MRV) systems for REDD+ (reductions in emissions from deforestation, forest degradation, forest conservation, sustainable forest management and the enhancement of forest carbon stocks).

Australia's NCAS integrates ground data and a time-series of remote sensing to estimate emissions and removals from deforestation and reforestation and shows one national scale approach to developing a reporting system. The intergovernmental Group on Earth Observations is working to develop the science, methods and protocols, and facilitate data coordination to provide for worldwide development of national MRV systems that combine ground and remotely sensed information.

2. Australia's NCAS

The NCAS was developed as a comprehensive system to report on Australia's land-based greenhouse gas emissions and removals (transfers to and from the atmosphere). The NCAS supports both estimation of emissions for Australia's international reporting obligations and also national policy development.

The NCAS integrates a wide range of spatially referenced data by means of a hybrid process and empirical model that estimates carbon stock changes and greenhouse gas emissions at fine spatial and temporal resolutions. Reporting includes all carbon pools and all principal greenhouse gases (CO2, CH4, and N2O).

The terrestrial ecosystem model implemented by the NCAS is the full carbon accounting model (*FullCAM*) (Richards 2001; Richards and Evans 2004). *FullCAM* is a carbon:nitrogen (C:N) ratio ecosystem model that calculates greenhouse gas emissions and removals for both forest and agricultural land using a mass balance approach to carbon and nitrogen cycling.

Because the primary concern is understanding the effect of changes in land cover and land use on greenhouse gas emissions, the modelling framework was designed to accommodate both forest and agricultural land uses, and any transitions between them. The model framework was fully integrated so that mass balance checks could be performed to ensure that all inputs, transfers, and emissions were properly reconciled at each time step in the simulation.

2.1 Climate

Climate variation has a significant effect on emissions in the short term and, because many management and reporting issues also relate to short term changes, it is important to be able to account for this variability. The process-based models used in *FullCAM* can use climate data to reflect this variability. The NCAS has developed monthly one kilometre climate grids from 1968 to 2004 for rainfall, minimum, average, and maximum temperature, evaporation, vapour pressure deficit, and frost (Kesteven et al. 2004). This climate grids are updated as new data become available.

2.2 Forest cover change

The importance of forest cover change to the pattern of greenhouse gas emissions and removals led to the need to develop a national time series of forest cover change showing both where and when change occurs. National coverages of Landsat satellite data (MSS, TM, and ETM+) across seventeen time epochs from 1972 to 2009 have been assembled and analysed for change (Caccetta et al. 2003). The historic cover and cover change information is important in two ways. First, the effects on greenhouse gas emissions from forest cover change are typically long-lasting, and historic activities may still contribute to current estimates. Second, emission and removal by current activity will be affected by site history. For example, a current deforestation event will probably generate fewer emissions if the forest cleared is secondary forest (regrowth after a previous deforestation) rather than a primary (mature) forest.

2.3 Crop yield

Crop yields are used in the model to determine several factors including:

- plant biomass (crop or grass) at a point in time, by use of ‘‘harvest indices’’ that relate total plant biomass to the commodity yield;
- how much plant biomass is removed from the site as product;
- the amount of root slough as input to soil; and
- the post harvest/grazing residues burnt, decomposed on soil surface or incorporated into soil.

2.4 Forest growth

Providing a dynamic, disturbance, and management responsive forest growth model for all of Australia’s forests was particularly challenging. The novel spatial modelling approach combines the strengths of both empirical and processed based modelling. The process elements of the model estimate the transfers between pools and account for climatic variability while empirical data set the calibration constraints. The empirical data that constrain the model reflect extensive field data (both already available and specifically collected).

Site and climate data are used in a process based model which is a simplified version of 3PG spatial (Landsberg and Waring 1997; Sands and Landsberg 2002). This produces spatially explicit continental estimates of productivity (Kesteven et al. 2004) in a time series site productivity index ranging from 1 (low) to 30 (high). The long-term average productivity defines long-term potential biomass accumulation while monthly productivity provides a relative temporal productivity anomaly.

The essence of this model is calculation of the amount of photosynthetically active radiation (APAR) absorbed by plant canopies. The factor converting APAR to biomass is reduced from the selected optimum value by modifiers depending on soil fertility, atmospheric vapour pressure deficits, soil water content, and temperature.

Long-term average productivity values were correlated to verified and spatially referenced observations of aboveground biomass in undisturbed forest stands at or near maturity. These biomass data were collated by means of an extensive search of published and unpublished data and ranged from arid shrublands (2 t ha–1) to tall wet sclerophyll forests (900 t ha–1) (Raison et al. 2003). The relationship between mass and long-term average productivity was then used to derive a map of potential site biomass at maturity (i.e. for long-term undisturbed stands).

2.5 Management data

Information gathered on management practices is documented in Swift and Skjemstad (2002) and Raison and Squire (2008). Databases were constructed for relevant geographic regions, further stratified spatially by relevant characteristics, for example soil and forest type, then classified in accordance with final non-spatial strata, for example crop type or tree species. The resulting databases cover a large range of possible scenarios with over 5,000 management systems, each comprising up to 30 specific practices.

These practices can be modelled to advance (or retard) growth for a specified period (Type 1 event, e.g. enabling five years growth in only four years) or increased growth over the entire rotation (Type 2 event, e.g. improve site productivity or change species) as per Snowdon (2002).

2.6 Fire

Fire plays a significant role in Australia’s natural and managed land-based systems. In *FullCAM* fire is modelled as an event with different characteristics depending on the nature of the event. Fire affects both live plants (i.e. trees and crops) and debris. During a fire each plant pool component (stem, bark, foliage etc.) is either retained to grow on into the future, emitted to the atmosphere, or becomes debris. Debris is either left unburnt, emitted back to atmosphere or transferred to the inert soil pool. The amount of material retained in the plant pools, emitted to the atmosphere, or moved to debris or soil pools depends on the species, and the type and intensity of the fire.

2.7 Coarse woody debris and litter

Initial estimates of coarse woody debris and litter (Harms and Dalal 2002; Murphy et al. 2002) are dynamically modelled to estimate change under typical species and management scenarios. *FullCAM* is run-in from the initial estimates with inputs to the debris and litter pools based on turnover from live pools (based on the forest-growth model) and the imposition of a known disturbance history (from the land cover change data).

This enables conversion of an uncertain historic initial estimate to a site and species specific estimate.

2.8 Soils

The spatial modelling of changes in soil carbon requires the following data:

- resource description (maps of soil type, carbon content, clay content, etc.);
- ancillary data (land-use, climate, residue inputs, etc.);
- field measurements for model calibration; and
- field measurements for model verification.

Substantial work was required to achieve consistency of data for pre-disturbance soil carbon content. This need was primarily derived from the differing analytical techniques used to assess the carbon content of soil samples (Skjemstad et al. 2000).

Testing the ability of the models to predict change in other locations on the basis of these calibrations was verified through an independent measurement program. The model calibration and verification results for agriculture can be found in Skjemstad and Spouncer (2002) and for forestry in Paul et al. (2002) and (2003).

2.9 Off-site products

When an agricultural or forest system is harvested or thinned, carbon stored on-site in plant or debris material can be moved off-site as a range of products. The time these products take to decay and return their carbon to the atmosphere depends on the species characteristics, type of product, and the amount of movement between product pools. Forest products in particular can provide an important longer-term store of carbon off-site and hence must be taken into account in a full mass balance model. Input data to estimate the flow of material into harvested wood products can be accessed via top-down national statistics (forest production and consumption reporting) or by modelled outputs from forest harvest activities (bottom-up). The top-down model has been progressively developed (Richards et al 2007) and has utilised a mix of input statistics from Australia's quarterly forest production and consumption statistics and industry estimates. Data for model calibration (e.g. processing losses, service life, and rates of recycling) have been variously drawn from available literature, industry estimates and expert opinion.

3. The GEO GFOI

A coherent international framework to support national forest carbon MRV systems is needed. An important step in that direction is the intergovernmental Group on Earth Observations' Global Forest Observations Initiative (GFOI) which is part of the Global Earth Observing System of Systems (GEOSS).

The operating context of the GFOI is that the key users of data and information are the governments developing national systems. These government systems will report into various international agreements and global assessments. GEO will promote the coordination of data collection, and associated work of documentation, inter-calibration and interoperability. GEO will work with various organizations to ensure there is comprehensive coverage and continuity of both satellite and ground data.

Two particular challenges faced by the GFOI were not features of developing the Australian NCAS. First, constant cloud cover over tropical areas that limits data availability from optical satellites, yet these form the substantive part of current data archives. There is growing interest in achieving *interoperability* between sensors to provide consistent time-series so that more recent cloud penetrating radar can improve the data coverage in future. Second, many countries either have, or are developing, systematic ground sampling for national forest inventories. The limited availability of such data in Australia led to a choice to place emphasis on models to integrate satellite and ground data. Different *integration* approaches will be needed where the systematic ground samples provide different forms of input data, although some form of modelling will still be essential.

The GFOI will support countries in their national carbon reporting consistent with the requirements of the UNFCCC. The components of the GFOI are:

- *Support to national governments:* applying consistent and comparable methods is fundamental to building the individually developed and comparable national systems.
- *Observations and measurement*: regular and routine (systematic) observations and measurements are essential for effective reporting. Data acquisitions need to include satellite, periodic ground, and other measurements. Continuity of data supply will be needed to ensure maintenance of time series and consistent reporting. Achieving interoperability between observations from different satellite sensors over time is crucial to ensuring time series consistency.
- *Methods and protocols for data collection, processing and integration:* GEO should promote and encourage the development of methods and protocols for data collection, processing and integration.
- *Continuing research and development:* GEO should promote coordinated research and development needed for continuous improvement of national forest information systems.
- *National capacity building:* to help governments develop national forest information systems, GEO will work in collaboration with other providers such as the FAO.

The detailed plan for the GFOI will be developed during 2011, and the planning process will, among other things:

- assess national capabilities for producing national forest information;
- identify strategies needed to improve national capabilities;
- identify potential sources of observations (satellite and in-situ) and associated data policies;
- provide a work plan with time lines and deliverables for the GFOI;
- identify recommendations to GEO Plenary 2011 and its participants for future action to implement the work plan; and,
- describe proposals for measuring success.

4. The Challenges of Integration and Interoperability

One of the key tenets of reporting under the UNFCCC is time-series consistency. This is so that emissions reductions can be monitored over time against a historic (1990) baseline. For satellite observations this means that different forms of satellite data may be available throughout the observations period. Also, with the more recent availability of cloud penetrating radar, some countries may choose to move from optical to radar data streams to access these cloud free observations. Developing methods of *interoperability* that allows for stable time series transition between data streams will be critical for time series estimates of forest cover and greenhouse gas emissions.

The remotely sensed data will need to be integrated with the ground measured information. There are many ways of doing this *integration*, typically using some form of carbon model.

5. Conclusion

Countries that developed national carbon accounting systems for the forestry components of the Kyoto Protocol can provide valuable lessons for the development of MRV systems for REDD+. Australia's use of wall-to-wall remote sensing in its NCAS pioneered approaches that are now being widely considered by developing countries for REDD+ MRV.

The challenge of coordination of both satellite and ground data to support such systems is being addressed by the GEO's GFOI. In addition, the GEO is researching technical solutions to interoperability in consistent use of different satellite sensors over time, and methods for integrating satellite and ground data.

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