Carbon cycle observations: challenges and opportunities

Helen Cleugh

Centre for Australian Weather and Climate Research – A partnership between CSIRO and the Australian Bureau of Meteorology

Summary

The cycling of carbon in the terrestrial biosphere is a key component of the climate system. Papers by Canadell et al (2006 and 2007) and Friedlingstein et al (2006) have clearly demonstrated how the trajectory of atmospheric CO_2 levels, and hence climate, depends on the ocean and land sinks, which currently take up about half of all anthropogenic CO_2 emissions but there are signs that this sink strength may be weakening.

The task of understanding and modelling the feedbacks between terrestrial carbon (and water) cycles, climate and human activities (including land management) are therefore a priority for climate science. And the need for quality observations of the terrestrial carbon and water budget, including fluxes, stores and atmospheric concentrations, to support model simulations and to monitor the response of the coupled carbon - climate system, must also be a priority.

This presentation will describe, and present key results from, the approach used to quantify the terrestrial carbon and water cycles in Australian landscapes at multiple space and time scales - combining atmospheric measurements, modelling and remote sensing. This approach is used to explore the elements and strategy for any future carbon cycle measurement program

Background

The underlying cause of global warming is the perturbation to the global carbon cycle caused by anthropogenic emissions of greenhouse gases (GHGs), which result from accelerating per-capita GDP and energy use over the last 100 years (Raupach et al, 2007). The response of the climate system is well known: atmospheric CO_2 concentrations are increasing at almost 2 ppm per year; the planet has warmed by 0.74^{o}C, and sea levels have risen by an estimated 17 cm, over the last century. The future trajectory of the global climate depends on how the carbon cycle – especially the land and oceanic uptake – responds to this changing climate which will in turn influence the airborne fraction of CO_2. The results of Friedlingstein et al (2006) illustrated that differences in the rate of carbon uptake by the land resulted in a spread of climate responses (temperature) that were as large as the range of IPCC emission scenarios. Recent publications by Canadell et al (2007) and Le Quere et al (2006) have suggested that the earth's natural sinks may be weakening – thus revealing sooner-than-expected the serious concerns raised by Canadell et al (2006) about the vulnerability of these carbon sinks, and the impact of these carbon – climate feedbacks on climate change projections.

The risks and research challenges posed by these results have been recognised by the Australian climate science community, who identified the terrestrial carbon cycle as a research priority, for example at a 2006 Workshop on Climate Change Science priorities where it was agreed that: ”*We know that the carbon cycle and its strength affects atmospheric concentrations of greenhouse gases. We also know that as climate changes, so too will various components of the cycle. Science has an important role in assessing the likely future changes to Australian terrestrial and marine environments and their influences*”, while the 2005 “Blueprint for Terrestrial Carbon Cycle Research” (hereafter, the Blueprint) articulated three research priorities: i)carbon budget dynamics (patterns of sources and sinks; processes and observations) across Australia; ii) the vulnerability of terrestrial carbon sinks especially to the effects of drought, fire and pests/diseases; and iii) representing the interactions between the carbon cycle and climate system in ACCESS.

Underpinning these stated priorities is the need for a strategic and integrated program of carbon (and energy, water and other biogeochemical cycles) budget observations – identified as a “cross-cutting” priority in the Blueprint. Such observations are needed to monitor trends and variability in the earth system; to compare against model predictions; and to provide the process understanding needed for model parameterisations. A terrestrial carbon cycle measurement program to address these needs must be multi-scale and have a clear strategy for combining a range of measurements (discrete/continuous; in situ/remotely sensed etc.) with models. The challenge for the Australian science community now is to articulate a coherent and integrated research program that implements these priorities, including a specification of what such a measurement program should comprise, what it needs to deliver, and how it could be achieved.

Terrestrial carbon and water budget measurements in Australian ecosystems: looking back and looking forward

Given this context, this paper provides an overview of the key results of a measurement program, initiated by the CSIRO Biosphere Working Group in 1999, and funded by CSIRO and the AGO, that has provided long-term measurements of the net carbon and water fluxes in several Australian ecosystems along with detailed terrestrial carbon budget measurements and modelling and some land-based, high precision CO_2 concentration measurements. These measurements, and the results, illustrate the following key pointers for future observation programs:

a) *Constraint of multiple measurements*: Measurements taken at a range of scales and of multiple components of the carbon budget, which are then integrated with models, have enabled us to place much greater confidence in any one measurement. This was a design strategy in our measurement program, and the results reinforce the value of this for any future integrated and quality-assured measurement program is to be embarked upon.

b) *Carbon (and water) budgets at ecosystem to continental scales*: These measurements have been used to calibrate and test remote sensing approaches for estimating the carbon fluxes at regional and continental scales (Leuning et al, 2005). Using remote sensing to provide continuous space/time distributions of the carbon fluxes, along with other recent developments such as NCAS and trend analyses of vegetation indices, mean that we have the necessary elements in place to begin the task of constructing time series of the carbon (and water) balances for specified ecosystems, regions and the continent.

c) *Combining terrestrial carbon budget with atmospheric measurements*: Combining an estimated terrestrial carbon source – sink distribution with atmospheric CO_2 concentration measurements (terrestrial and baseline) is needed for a complete observation-based assessment of the regional carbon budget dynamics for parts, or maybe all, of the Australian continent. Such information not only provides us with an estimate of the regional and continental carbon fluxes, but also the affect and perhaps attribution due to climate and land management drivers.

d) *Continuous, ecosystem-scale measurements of fluxes*: For parameterising and testing land surface models used in climate models, such as CABLE in ACCESS, and to capture trends and variability at all timescales, it is imperative to have continuous measurements. Net carbon and water fluxes obtained from flux towers are temporally continuous and are spatially averaged across a plant canopy. The research has developed theoretically-sound methods to reduce the bias in NEE estimates from flux tower measurements (van Gorsel et al, 2006). Fluxnet is a global network of > 400 flux towers sampling a large diversity of bioclimates which provides a data set of ecosystem-scale, continuous net carbon fluxes. Current work demonstrates the potential of this large and global database to improve and parameterise land surface schemes for climate models, such as CABLE.

Drawing from these results and points, the presentation will conclude with a strawman view of what an integrated measurement program would comprise and what it could deliver

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