Chapter 2
Observing a Vulnerable Carbon Cycle

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2.1 Introduction

The carbon cycle and indeed the entire earth system are now inextricably linked with human activities (Global Carbon Project 2003; Steffen et al. 2004; Field and Raupach 2004), so that the ‘carbon–climate–human system’ constitutes a single, coupled entity in which interacting processes link all of its major components. Linking processes of primary significance include

1. The human drivers of energy consumption and land-use change, through increases in both population and per capita consumption
2. The role of human energy systems as sources of CO\(_2\) and other greenhouse gases (GHGs)
3. Land-use change (deforestation, increases in agricultural and urban land use) and its consequences for both GHG emissions and resource (water, land, ecosystem) condition
4. Climate forcing by CO\(_2\) and other GHGs, following from drivers 1, 2 and 3
5. The changing roles of the ocean and the terrestrial biosphere as sinks and sources of CO\(_2\) and other GHGs, driven by the disequilibrium of the earth system through human activities
6. Impacts of climate change through declines in resource condition and human well-being
7. Attempts by human societies to reduce their impact on the global environment, for example, through reductions in GHG emissions to avoid ‘dangerous climate change’ (Schellnhuber et al. 2006)

Through the first six of these processes humankind is unintentionally influencing the earth system, while the seventh is an effort to manage global-scale human impacts on the earth system by mitigating their causes.

An integrated global carbon observation system (Ciais et al. 2004) is a contribution to monitoring the first six of the above processes, and bringing about the seventh. These underlying motivations lead to two broad goals for global carbon observations, respectively oriented towards understanding and management. The former goal is to provide increased understanding of the cycles of carbon and
related entities (water, energy, nutrients) in the earth system, contributing to our ability to diagnose trends and to predict future evolution of the carbon–climate system over timescales of decades to centuries. The latter is to provide the global-scale observations of carbon fluxes and GHG emissions needed to manage the carbon cycle, through emissions reduction programmes based on incentive, regulatory or trading mechanisms. Between them, these two goals largely determine the necessary broad attributes of a global carbon observing system. A recent analysis (Raupach et al. 2005) identified seven main attributes for terrestrial carbon observation, which (with slight extension) provide a broad specification of attributes for a complete global carbon observing system. These seven are (1) scientific rigour; (2) global scope and consistency; (3) spatial resolution sufficient to resolve and monitor all important processes, especially carbon fluxes associated with human land use and energy systems; (4) temporal resolution sufficient to monitor variability in fluxes from weather to climate timescales; (5) integrated monitoring of all relevant entities [CO₂, CH₄, CO, volatile organic compounds (VOCs), black carbon, together with fluxes of water, nutrients and other entities relevant in modulating carbon fluxes]; (6) process discrimination (for instance, between anthropogenic and non-anthropogenic fluxes, and between contributions to net fluxes such as assimilation, autotrophic and heterotrophic respiration); and (7) quantification of uncertainty.

Here, we discuss the implications of carbon–climate vulnerabilities for the attributes of an integrated carbon observation system. By ‘carbon–climate vulnerability’ we mean a positive, disturbance-amplifying feedback between an aspect of the carbon cycle (a pool or flux) and physical climate, including atmosphere, oceans and the hydrological cycle. In particular, carbon–climate vulnerabilities are processes causing global warming through the enhanced greenhouse effect to be larger than it otherwise would be in their absence.

Two ways have been used recently to quantify carbon–climate vulnerability in the above sense. The first is a risk-assessment methodology (Gruber et al. 2004, henceforth G2004) involving heuristic, judgement-based estimates of the releases of carbon to the atmosphere from several terrestrial and oceanic pools under projected changes (to 2100) in temperature, ocean circulation and other physical climate properties. G2004 expressed the results of the assessment as ellipses on a plane with axes defined by the mass of carbon released and a qualitatively judged probability of release (with small releases having high probability and vice versa). This approach is a valuable beginning, but cannot properly quantify carbon–climate feedbacks by estimating the extent to which a carbon release is modified by the extra climate change induced by the release itself.

The second, much more quantitative approach is through the use of fully coupled carbon–climate models. Eleven such models were compared in the recent Coupled Climate–Carbon Cycle Model Intercomparison Project (C₄MIP) (Friedlingstein et al. 2006). The models included full physical climate, ocean carbon biogeochemistry responsive to temperature and atmospheric CO₂, and terrestrial carbon dynamics responsive to light, water, temperature and CO₂. All models were run from 1850 to 2100 under a prescribed emissions scenario (the IPCC SRES¹ A2 scenario; see later

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¹IPCC, Intergovernmental Panel on Climate Change; SRES, Special Report on Emissions Scenarios.