

Geographic and Temporal Variation of Carbon Exchange by Terrestrial Ecosystems and Their Feed-backs with the Climate System

Riccardo Valentini
Dipartimento di Scienze dell'Ambiente Forestale e delle sue Risorse
Università degli Studi della Tuscia
Viterbo Italy
Email: rik@unitus.it

Abstract

Across the globe there is great temporal and spatial variability in the rates and cumulated carbon exchanges by biomes due to temporal and spatial gradients in climate, available resources, plant structure and function, land use and soil development. In this paper we address how geographic variations in climate and vegetation affect net carbon exchange of terrestrial ecosystems and how likely climate changes could affect such processes. This analysis is performed for each world's major biomes—tropical, temperate, and boreal forests, savannas, shrublands, grasslands, wetlands, tundra and deserts—by surveying published data from the FLUXNET network. A mechanistic interpretation is provided by decomposing net ecosystem productivity (NEP) into its constituent components—gross primary productivity and ecosystem respiration.

Introduction

One of the hallmarks of contemporary research in the biogeosciences has been an ability to observe the carbon exchanges of the biosphere, through the long term monitoring of CO₂ concentration at Mauna Loa (Keeling and Whorf, 1996) and an expanded networks of CO₂ monitoring stations across the globe (Tans et al. 1996). On a global basis, the net amount of carbon exchanged between the terrestrial biosphere and the atmosphere is the sum of many diverse parts— tropical, temperate, and boreal forests, savannas, shrublands, grasslands, wetlands, tundra and deserts. Due to differences in their respective land area and their physiological potential to assimilate CO₂ and respire stored carbon compound, each of the sited biomes do not contribute equally to the global carbon budget (Melillo et al., 1993), nor will they respond similarly to environmental perturbations.

On an annual time scale, the net exchange of carbon dioxide between a terrestrial ecosystem and the atmosphere (NEP) can be defined as the difference between gross primary productivity (*GPP*) and ecosystem respiration (R_{eco}):

$$NEP = GPP - R_{eco} \quad (1)$$

GPP represents the flux of carbon that is assimilated by all the plants in the ecosystem through photosynthesis. Ecosystem respiration consists of autotrophic respiration by the plant stems, roots and leaves (R_{auto}) and heterotrophic respiration by the microbes and soil fauna (R_{hetero}):

$$R_{eco} = R_{auto} + R_{hetero} \quad (2)$$

As a rule of thumb, autotrophic respiration constitutes about half of *GPP* (Gifford, 1994; Waring et al., 1999) and two-thirds of ecosystem respiration (Law et al., 2002; Falge et al., 2002).

Available light energy and temperature are the fundamental drivers of photosynthesis at the leaf scale, whereas photosynthesis at the ecosystem scale correlates leaf area index, nitrogen content of leaves, rainfall and humidity. With regards to leaf respiration, temperature is the fundamental environmental driver. However, as one moves upscale to the dimension of plant and ecosystems, one finds that respiration varies with body size, phenology, soil moisture and net primary productivity (Amthor, 199x; Enquist et al., 2002; Falge et al., 2002). Consequently, the amounts of NEP , GPP and R_{eco} and their sensitivity to environmental forcings will vary spatially due to differences in climate and available resources and temporally as the climatic drivers change with the seasons.

Biogeochemical models provide one of the main tools for assessing the net exchange of carbon between the terrestrial biosphere and atmosphere by their ability to assess Equations 1 and 2 at continental and global scales (Melillo et al., 1993; Foley et al., 1996; Bonan, 1998; Cramer et al., 1999). These models account for the diversity and complexity of the natural world by dividing the terrestrial biosphere into broad vegetation classes—plant functional groups—that are defined by their function and climate (Holdridge, 1967; Woodward, 1984; Bonan, 2002). The type and amount of vegetation at a particular location is evaluated either diagnostically using remote sensing information derived from satellites (Running et al., 1999) or prognostically using dynamic vegetation models (Haxeltine and Prentice, 1996; Foley et al., 1996). This information is then used to parameterize algorithms that compute photosynthesis and respiration (Hunt et al., 1996; Bonan, 1998; Cramer et al., 1999). Finally, the photosynthesis and respiration algorithms are evaluated as a function of environmental variables such as light, temperature and soil moisture; these inputs are derived either by interpolating weather measurements or numerically with weather/climate prediction models.

One application of biogeochemical models is to examine the annual sums of carbon exchange across broad geographical regions based on contemporary weather. Another application involves the performance of numerical experiments to examine how the carbon cycle responds to perturbations in environmental variables or land surface properties. With respect to the topic of this chapter, Churkina and Running (1998) used the BIOME-BGC model to produce a global map showing where net primary productivity (NPP) is sensitive to light, temperature or soil moisture. They report that NPP is light and temperature limited in northern climates and biomes, NPP has a low degree of light and water limitation in tropical and humid temperate regions, and in semi-arid climates, NPP tends to be water limited (Figure 1).

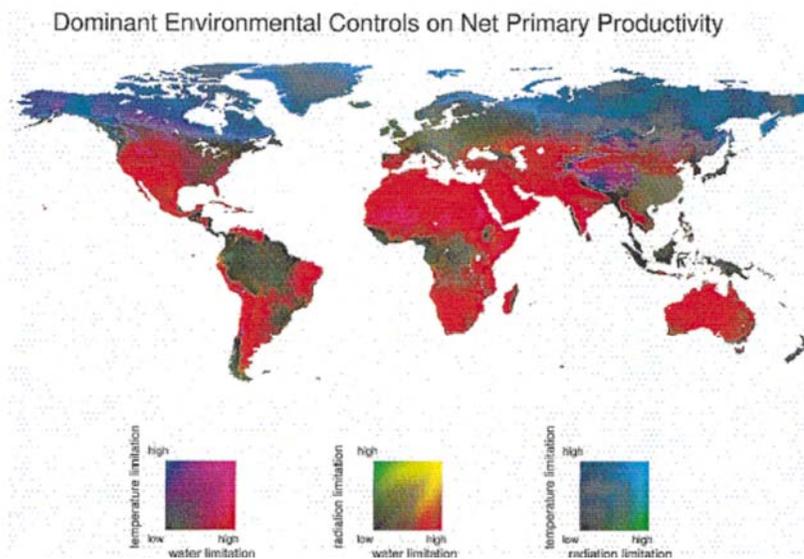


Figure 1 Geographic distribution of the dominant environmental factors governing NPP . This figure refers to an annual basis and does not consider seasonal variations in environmental controls of NEP . After Churkina and Running, 1998

To construct a global view of the environmental factors controlling NEP , refinements to the analysis shown in Figure 1 are needed. To evaluate the geographical variability in NEP and its sensitivity to environmental forcings, the next generation of biogeochemical models must be able to: 1) assess how geographic variations in climate and vegetation affect the responses of GPP , and R_{eco} , to environmental forcings, as well as NPP ; and

2) assess how GPP and R_{eco} respond to environmental switches or acclimate over the course of the growing season as leaves age or certain weather patterns persist.

At present, the FLUXNET community is producing NEP data on hourly to interannual time scales. Since measurements are being made at over 150 sites world-wide, the network encompasses a wide range and combination of climate zones and plant functional types (Running et al., 1999; Baldocchi et al., 2001). Consequently, the FLUXNET project has the potential to provide new information that can be used to refine the algorithms in biogeochemical models.

Scientists involved in the FLUXNET network measure NEP directly with the eddy covariance method. GPP and R_{eco} are deduced, subsequently, using a combination of daytime and nighttime eddy covariance measurements to solve Equation 1 (Law et al., 2002; Falge et al., 2002). So together, each FLUXNET field site has the potential to produce information on the seasonal of NEP , NPP , GPP and R_{eco} and can assess how these metrics respond to weather, plant and soil factors.

In this paper, we distill published data produced by FLUXNET scientists and evaluate the environmental factors that control NEP of ecosystems distributed across the globe over the time course of a year. We will address cases for the dominant land types: 1) temperate broadleaved forests, 2) boreal and temperate coniferous forests, 3) grasslands, 4) Mediterranean woodlands, 5) agricultural crops and 6) northern wetlands. Highlighted in this analysis will be the role of environmental switches, such as leaf on/leaf off; drought, frost (spring/fall), the presence or absences of snow, and, in wetlands, the height of the water table. One goal of this analysis is to generate a set of rules that will guide us to model NEP better by providing information to a new generation of biogeochemical models that use artificial neural networks (Papale et al 2003; Bouten et al. 2002) to model NEP .