Linking carbon storage in terrestrial ecosystems with other climate forcing agents:
A synthesis allowing for effective carbon dioxide stabilization policies

Short title: Terrestrial Ecosystems and Climate Policy

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Summary

Reforestation, afforestation, and avoided deforestation mitigation options influence climate at local to global scales by mechanisms in addition to their effect on stabilizing atmospheric carbon dioxide levels. In some cases, for example, climate forcing from concurrent changes in albedo, evapotranspiration, and aerosols may have a larger impact regionally and globally than the net effects of greenhouse gases, yet these mechanisms are not accounted for in current policy frameworks such as the Kyoto Protocol. We propose a series of three meetings, bringing together ecosystem ecologists, climate scientists, and policy experts to synthesize recent work on tradeoffs between biogeochemical and biophysical forcing agents associated with land cover change. In a second step, we plan to draft a policy perspective that reevaluates the role of terrestrial ecosystems in climate policy.

1. Problem Statement

Tree planting is being aggressively pursued at local, state, national, and international levels as a means to slow greenhouse gas accumulation and climate warming. In December of 2006, for example, the California Public Utilities Commission granted Pacific Gas and Electric permission to start a program (ClimateStart) to allow consumers to offset their electricity-related CO_2 emissions via state-wide refforestation projects. In January of 2007, Dell Computers launched the "Plant a tree for me" program with Carbonfund.org to allow users to offset the carbon impacts associated with their use of information technologies. These and many other efforts build upon the framework described by article 3.3 of the Kyoto Protocol that allows countries to use afforestation and reforestation projects in a limited way to meet their emissions reduction targets from 1990 through 2012. The viability of refforestation and afforestation in the U.S. and Europe as successful greenhouse gas stabilization strategies has been bolstered by an influential line of atmospheric research over the last two decades that suggests that contemporary northern hemisphere terrestrial ecosystems are a moderate-sized carbon sink [*Tans et al.*, 1990; *Gurney et al.*, 2002; *Stephens et al.*, 2007].

Within the policy community, afforestation, reforestation, and avoided deforestation are currently viewed as a means to sequester atmospheric carbon dioxide and thus as one of many options currently available to stabilize future levels of greenhouse gases [e.g., *Pacala and Socolow*, 2004; *Chameides and Oppenheimer*, 2007; *Gullison et al.*, 2007]. Yet a growing body of scientific literature provides evidence that carbon sources and sinks are inseparably linked with changes in ecosystem function that influence climate via a number of other mechanisms *[Marland et al.*, 2003], including N_2O and CH_4 [*Robertson et al.*, 2000], aerosols [*Ramanathan et al.*, 2001], and changes in surface biophysics [*Pielke et al.*, 2002]. In arctic and boreal regions, for example, increasing forest cover may increase carbon storage, but concurrently decrease surface albedo because trees are often darker than the grasses and shrublands they replace (Figure 1). This albedo-linked warming may exceed cooling caused by carbon storage over a period of decades, so that afforestation projects in these regions could have the unintended consequence of accelerating both regional and global climate warming [*Betts,* 2000; *Chapin et al.*, 2005; *Randerson et al.*, 2006; *Bala et al.*, 2007]. In temperate regions, modeling work suggests that albedo and carbon storage mechanisms sometimes cancel one another, at least when quantified in terms of global mean surface air temperature [*Brovkin et al.,* 2004; *Bala et al.*, 2007]. Even in temperate regions that do not have periods with sustained snow cover, differences in surface heating from forest cover change may be substantial because of large albedo differences between different vegetation types and exposed soils (Figure 2).

In the tropics, biogeochemical and biophysical changes associated with deforestation may reinforce one another, accelerating regional and global warming trends [*Betts, et al.*, 2004; *Bala, et al.*, 2007]. In the context of these comparisons, it is worth noting that most studies have focused on biophysical vs. CO_2 tradeoffs; the effects of other forcing agents, including ozone, direct and indirect aerosol effects, and other greenhouse gases have not yet been assessed quantitatively.

In parallel, afforestation, deforestation, and other land-cover shifts strongly influence temperatures through changes in evapotranspiration [*Bosch and Hewlett* 1982, *Zhang et al.* 2001]. Canopy interception, for instance, tends to be relatively small in grasslands but can account for 10-20% of rainfall in hardwood systems and 20-40% in conifer plantations [*Levia and Frost*, 2003]. Not only do such changes affect evapotranspiration, they alter streamflow and ecosystem services in general [*Jackson et al.*, 2005]. Annual runoff, for example, is reduced on average by 44% and 31% when grasslands and shrublands are afforested, respectively [*Farley et al.*, 2005]. Regional effects on temperature through water use depend on the location, extent, and patchiness of afforestation and deforestation and operate through changes in albedo, roughness length, and water transport properties from soil to the atmosphere, including leaf area index, stomatal conductance, and rooting depth.

These relatively new science developments pose challenging questions with respect to the treatment of terrestrial ecosystems in post-Kyoto climate negotiations. Accumulating data strongly suggest that the net climate effect of carbon sequestration in terrestrial ecosystems depends not just on changes in the carbon balance of an ecosystem, but also on changes in the ecosystem's albedo, production of aerosols, and evapotranspiration. Given this background, outstanding questions include:

1. In what locations (tropical, temperate and boreal) and with which kinds of forests (deciduous versus evergreen) does changing forest cover lead to net climate cooling?
2. Given current knowledge of the multiple climate factors and ecosystem services affected by reforestation and afforestation, is the science community in a position to recommend them as viable mitigation options for countries in temperate and boreal regions?
3. Can and should the policy community move from carbon to radiative forcing (or another more general currency) for evaluating the efficacy of policies designed to slow global warming?

2. Proposed Activities

We propose to form a working group at NCEAS to reduce the science uncertainties associated with the net climate impacts of changing land cover and to develop policy recommendations with respect to the representation of terrestrial ecosystems in climate policy. We propose to have three meetings - each for approximately 3-4 days. At the first meeting, we will work on manuscripts that synthesize recent science observations and modeling results related to biophysical and biogeochemical tradeoffs associated with land cover change. One activity of this synthesis will be to describe the conditions in which afforestation, woody plant encroachment, and other mechanisms that increase the abundance of trees will result in a net cooling in temperate ecosystems. Temperate systems are where many incentives for carbon sequestration are being considered and for which large uncertainties exist in the net effects of afforestation. At the second meeting we will continue with our science synthesis activities and begin work on a policy perspective for *Science* that address the questions listed above (and that draws upon insight from our science synthesis). At a third meeting we plan to finish the policy perspective.

Science analysis and synthesis. Our primary objective will be to develop a conceptual framework for evaluating whether terrestrial carbon sinks accelerate or slow global warming. Examples of land cover change that accumulate carbon but have ambiguous net effects on climate include agricultural abandonment in the northeastern U.S., woody encroachment in the southwestern U.S., and fire suppression. Key issues that will be addressed in our synthesis include the time and length scales of climate impacts associated with different climate forcing mechanisms and current limits to our understanding imposed by uncertainties in observations and model parameterizations. Surface air temperature increases caused by decreasing surface albedo, for example, are concentrated regionally with a length scale of ~ 500-1000 km, whereas temperature increases caused by greenhouse gases are distributed more uniformly across the globe (and much more diffusely for the same radiative forcing) [*Ramaswamy et al.*, 2001]. As a result, countries that invest heavily in afforestation/reforestation may increase air temperatures within their borders but cool globally. The policy implications of this tradeoff have not been yet fully appreciated.

A specific goal will be to assess uncertainties associated with the net climate effect of carbon sequestration in temperate regions where uncertainties appear to be highest. As described above, a recent model analysis suggests gaining or losing forest cover in temperate regions may have a neutral effect on global air temperatures. To more quantitatively evaluate whether temperate afforestation/reforestation has positive climate benefits, a more systematic analysis of the following factors needs to occur:

a) The type of land that is being converted, including its initial albedo and roughness

b) The albedo of the new land cover – for example, a deciduous broadleaf forest can have an albedo that is double that of an evergreen conifer forest

c) The amount of water required and available for the land cover conversion and ultimately for cooling via transpiration and cloud formation

d) The amount of fertilizer required for the conversion (and subsequent greenhouse gas production)

Important observational constraints on albedo will come from NASA's MODIS instrument on Aqua and Terra and FLUXNET observations. We will use the MODIS subsetting tool at the NASA ORNL DAAC to extract albedo at specific sites and across carbon storage gradients (http://www.modis.ornl.gov/modis/NorthAmerica_Tool/index.cfm). As a part of our time and length scale analysis, we plan to explore micro to regional to global scale consequences of afforestation in urban areas.

Prior to this meeting (during the fall of 2007), the working group will begin to compile observations of albedo and other biophysical variables such as roughness and net radiation for the source/sink mechanisms described above. In parallel, we will analyze output from climate model simulations, including those published by *Jackson et al.* [2005] and *Bala et al.* [2007]. We also plan to compare, for example, model estimates of albedo with observations along important carbon gradients. This work as it links to climate change is currently supported, in part, by seed money from the southwestern and southeastern sections of National Institute for

Climatic Change Research. The working group will share information during 2-3 teleconferences prior to this first meeting. ***We would also like to request a postdoctoral scholar from NCEAS to work with us on this science synthesis.*** The postdoctoral scientist would help compile datasets of albedo and other climate-related variables for different land cover types using MODIS and Fluxnet observations. She would also extract this information from existing model simulations.

Policy perspective. In a second step, we plan to write a policy perspective for *Science* that addresses the role of afforestation, reforestation, and avoided deforestation in the context of climate negotiations for the post-Kyoto era (2012 and beyond). Does our review and synthesis of the contemporary science (our first step described above) suggest that afforestation and reforestation in temperate regions should be viewed on equal footing with other CO_2 stabilization approaches such as investments in renewal energy? If avoided deforestation in tropical regions has climate benefits, yet afforestation in temperate countries is climate neutral, how do we separate these regions for the purposes of climate policy? What are recommendations for the community to move from carbon accounting to a framework that integrates across the different climate forcing agents and takes into account carbon storage effects on ecosystem services? More broadly, in the context of future climate policy, what type of scientific understanding is most useful to policy makers to assess climate neutral mitigation policies involving terrestrial ecosystems?

3. Participants

Our working group for the first meeting includes a graduate student (Ray Anderson from UC Irvine), two assistant professor faculty members (Lara Kueppers from UC Merced and Noah Diffenbaugh from Purdue), and two international participants (Pep Canadell from CSIRO and Annette Freibauer from Max Planck Institute for Biogeochemistry) (Table 1). For the second and third meetings, we plan to expand our group to include two more policy experts (for example, Maria Jose Sanz with the UNFCC in Bonn, Bernhard Schlamadinger from Joanneum Research in Austria, or Paulo Roberto De Souza Moutinho from IPAM - Instituto de Pesquisa Ambiental da Amazônia in Brazil).

Although our working group is relatively large (17-19), we believe this larger group is necessary to bring together the three communities (climate scientists, ecosystem ecologists, and policy experts) needed to make a conceptual advance in the way terrestrial ecosystems are treated in climate policy. Randerson will serve as the technical liaison with NCEAS technical staff and for ensuring that the requirements of the NCEAS data and information policy are met.

Table 1. List of Academic Participants

	Name	Affiliation	Area of Expertise	Confirmed
1	Ray Anderson	UC Irvine	Graduate student; water use and climate impacts of agriculture	yes
2	Dennis Baldocchi	UC Berkeley	Biometeorology and ecosystem ecology	yes
3	Gordon Bonan	National Center for Atmospheric Research	Ecological climatology	yes
4	Ken Caldeira	Carnegie Institution of Washington	Coupled carbon-climate modeling, long-term carbon cycle dynamics	yes
5	Pep Canadell	Global Carbon Project and CSIRO	Global carbon cycle science and policy	yes
6	Ruth DeFries	University of Maryland	Tropical deforestation	yes
7	Bob Dickinson	Georgia Institute of Technology	Biosphere-atmosphere interactions	yes
8	Noah Diffenbaugh	Purdue	Regional biosphere-atmosphere modeling	yes
9	Chris Field	Carnegie Institution of Washington	Global carbon cycle science and policy	yes
10	Annette Freibauer	Max-Planck-Institute for Biogeochemistry	Post-Kyoto land use, land cover change, and forestry science and policy	invited 7/16
11	Rob Jackson	Duke University	Water resources and ecosystem function	yes
12	Lara Kueppers	UC Merced	Regional climate effects of land cover change	yes
13	Beverley Law	Oregon State University	Regional ecosystem-atmosphere carbon exchange	invited 7/15
14	Diane Pataki	UC Irvine	The role forest cover in urban biogeochemistry and climate	yes
15	Janet Peace	Pew Center on Global Climate Change	Climate policy and economics	invited 7/15
16	Annie Petsonk	International Counsel, Environmental Defense	International environmental policy	yes
17	Jim Randerson	UC Irvine	Climate effects of biomass burning	yes

4. Timetable

Period	Activity
9/07-1/08	Compilation of albedo observations for key temperate disturbance gradients Compilation and distribution of bibliography and pdfs of relevant papers Coordination and data sharing via teleconferences (in September and November). Randerson, Jackson, and Canadell put together a draft outlines.
1/08	***Working group meeting 1: Science analysis and synthesis*** At this meeting we will focus on analysis and writing with the goal of putting together a draft of a synthesis paper on carbon vs. other climate drivers
3/08	Telecon to discuss writing assignments and progress. Continued analysis of remote sensing observations and of existing RAMS and NCAR model simulations
6/08	***Working group meeting 2: Finish science synthesis and start policy perspective***
7/08	Telecon to discuss manuscripts and to coordinate writing assignments
10/08	***Working group meeting 3: Finish policy perspective manuscript***
12/08	Meet at the American Geophysical Union fall meeting in San Francisco to address reviewer comments and to communicate science & policy findings to the broader community and to the media

5. Anticipated results and benefits

Key deliverables will include:

1. 1-3 science synthesis paper(s) on tradeoffs between biogeochemical and biophysical impacts of climate associated with important carbon source/sink mechanisms.
2. A policy perspective for *Science* that addresses how the non-carbon climate consequences of reforestation, afforestation, and avoided deforestation should be addressed in climate policy

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