The Unintended Climate Consequences of Carbon Sequestration in North American Forests

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Background

Planting forests is one of few readily available and proven approaches to mitigating climate change through the sequestering of atmospheric carbon dioxide (CO2). In order to avoid a doubling in the concentration of atmospheric CO2 from preindustrial values by mid-century will require a multitude of technologies and approaches - carbon sequestration through forest planting being one of the more practical ones. It has been estimated that the establishment of 400 Mha of new forests in temperate latitudes and 300 Mha of plantations on non-forested land would account for an equivalent of 1 GtC/year of reduced carbon emissions over the life of a forest. Policies currently being proposed and debated in Congress have carbon sequestration as a central component of a national plan for mitigating climate change (e.g., Cap and Trade), however there is considerable uncertainty over whether afforestation/reforestation will actually do more harm than good. Planting a forest may decrease the surface reflectivity resulting in greater net radiation being absorbed at the surface and thus, surface warming. In some cases this warming can more than offset the climate benefit derived from carbon sequestration. A number of theoretical studies have suggested that planting forests in temperate and high latitudes could actually have the unintended consequence of warming the planet by decreasing the surface reflectivity.

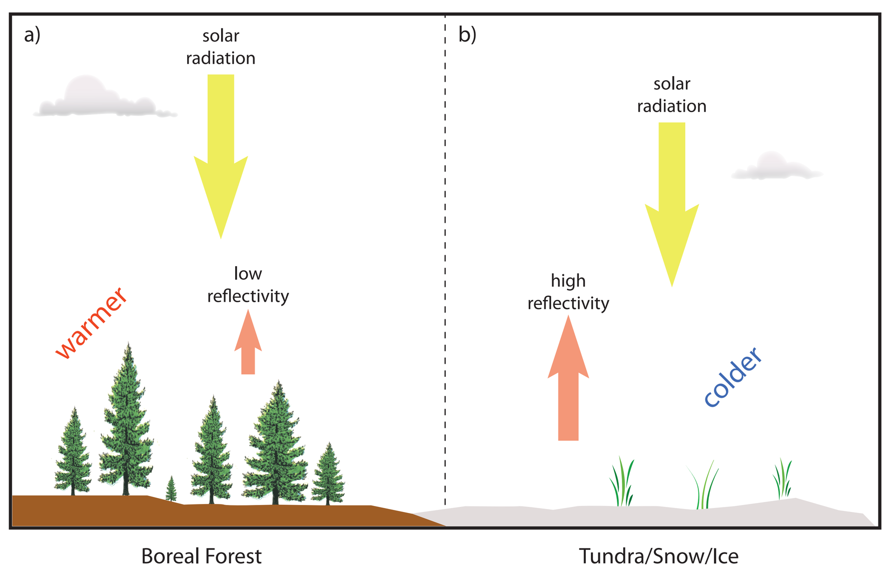

Figure 1. Forest placement can contribute to atmospheric warming from an albedo-driven vegetation feedback.

From a biogeochemical perspective, placement of a forest benefits the climate system by sequestering carbon and reducing the atmospheric concentration of carbon dioxide. This results in a reduction in the radiative forcing of the planet, and a lower global temperature. In contrast, from a biophysical perspective, a forest landscape (Fig. 1a) has a lower reflectivity relative to a non-forested landscape (Fig. 1b), especially when the land surface is covered by snow during the winter months. Sunlight imposed on the forested landscape will result in less radiation being reflected back to the atmosphere, thus causing a net warming as the trees absorb more radiation. For a non-forested landscape, more incident sunlight will be reflected back to the atmosphere, thus causing a net cooling.

The key to providing a benefit to the climate system through forest placement is to maximize the carbon sequestration potential of the forest while at the same time minimizing the biophysical impacts that act to offset the climate benefit.

The goal of this project is to identify the feasibility of large-scale forestation with the end goal of sequestering sufficient amounts of carbon in the biosphere so as to reduce the atmospheric concentration of carbon dioxide and global warming.

It is posited that four main factors influence whether forest placement at a particular location can benefit the climate through maximizing the sequestration potential and minimizing the detrimental biophysical impacts from the surface reflectivity:

1. Climate
2. Forest Age
3. Fraction Cover
4. Forest Species

To evaluate the relative importance of these factors, a dynamical vegetation model is used to simulate the placement of large-scale forest lands with the intent of benefiting the climate system.

Vegetation Modeling

The Integrated BIosphere Simulator (or IBIS--Foley et al. 1996; Kucharik et al. 2000) is a comprehensive model of land surface and terrestrial ecosystem processes and was developed for the purpose of studying the response of natural vegetation and carbon, nitrogen, and water cycles (e.g., runoff) to various environmental drivers. The model is designed around a hierarchical conceptual framework, and includes several sub-models that are organized with respect to their characteristic temporal scale (Figure 2). IBIS simulates the energy, water, carbon, and momentum balance of the soil-vegetation-atmosphere system on a relatively short time step (~30 minutes) and at a spatial resolution dependent on driving datasets (e.g., climate and soil texture). IBIS has been enhanced for this project to include a forest age class scheme to capture carbon sequestration rates as a function of forest age. In addition, IBIS is currently being modified to include representation of hybrid poplar forests in order to determine the viability of this species for climate mitigation.

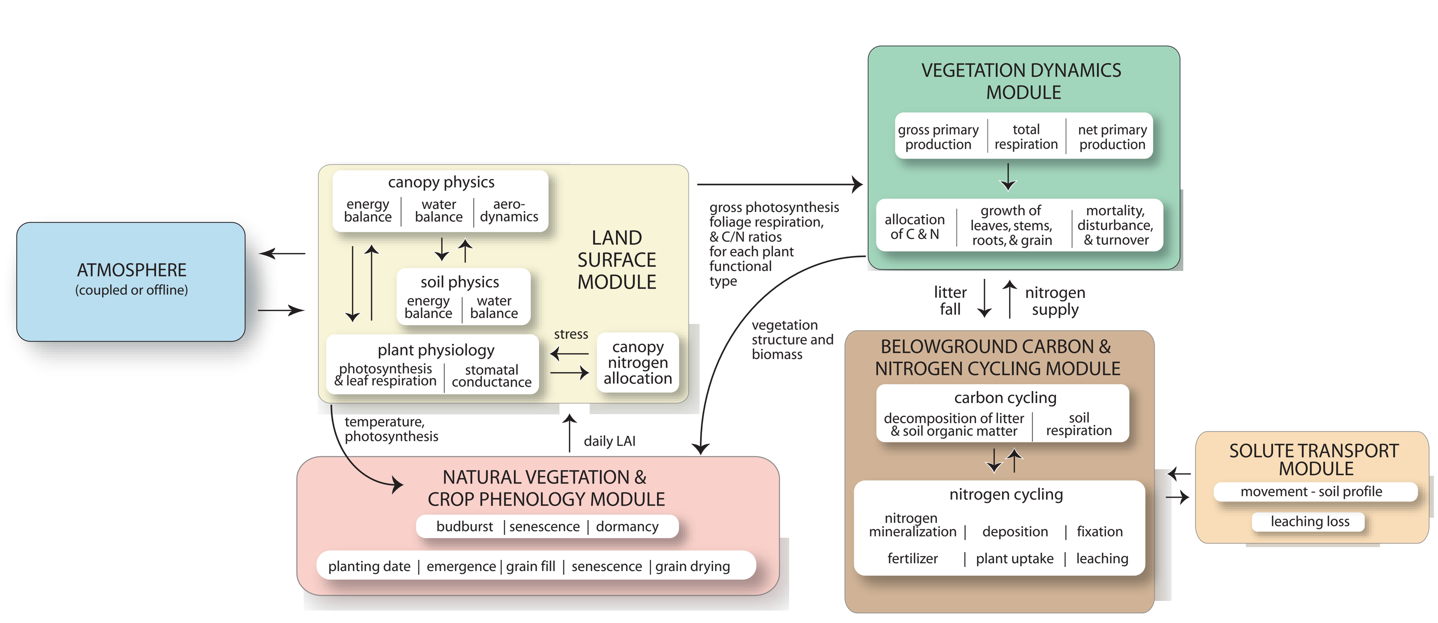

Figure 2. Schematic of the Integrated BIosphere Simulator (IBIS).

Preliminary Findings

The process leading to establishment of a forest with a goal of providing the maximum climate benefit is dependent on a number of factors:

Climate – a successful forest site is one in which the climate is favorable for the species being established. Cloudy locations result in less influence of the surface reflectivity, which leads to less energy absorbed at the surface and a cooler climate (Fig. 3). In addition, increased cloud cover can contribute to more diffuse radiation, which enhances photosynthesis since diffuse radiation is more effective at illuminating shaded leaves inside the canopy as compared to direct radiation.

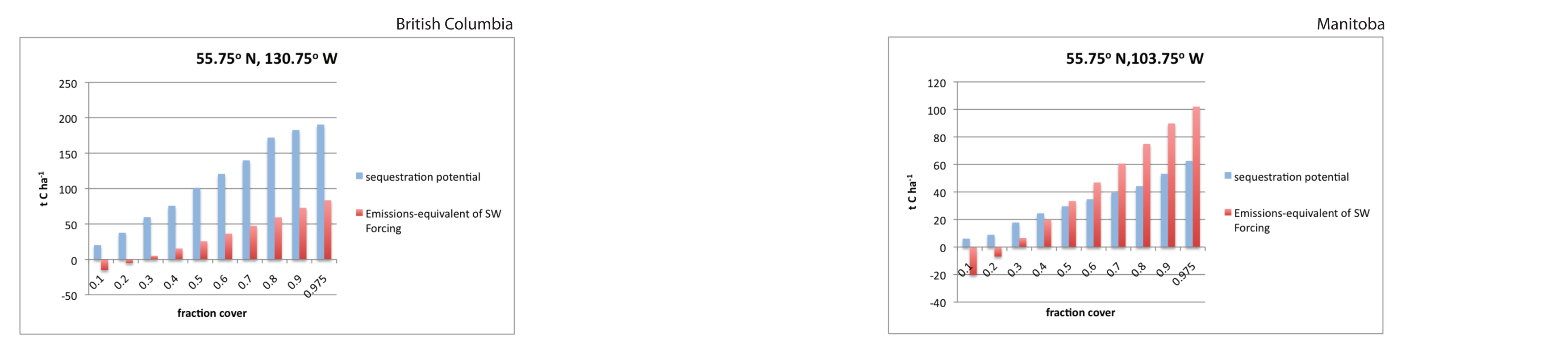

Figure 3. IBIS simulations highlighting the importance of climate on the choice of forest placement. The graphs depict the carbon sequestration potential (in blue) and the emissions-equivalent of shortwave radiation forcing (in red) for a 50-year period that is meant to represent a typical stand lifetime (planting to harvest). With a larger forest fraction, the greater the sequestration potential, but the larger the radiative forcing effect due to lower reflectivity. The western Canada site is an ideal location for afforestation/reforestation as the sequestration potential far exceeds the detrimental radiative changes and the net effect is a benefit to the climate. The central Canadian site, however, is not ideal since low sequestration rates cannot offset the large radiative influence except for very small forest fractions (< 0.5). The western Canada site is also ideal when compared to the central Canada site because of greater year round cloud cover that reduces incoming solar radiation and thus, the radiative influence of the forest relative to a grassland. These simulations suggest that the British Columbia site would be a more ideal location for placement of a forest for carbon sequestration purposes.

Fraction Cover – the fraction of an area covered by the forest canopy as compared to the underlying surface can influence the reflectivity of the surface, and thus, the amount of warming (Fig. 4). Proper placement of trees in a plantation can minimize the impact of the surface reflectivity and improve production, as trees do not need to compete for sunlight if spaced sufficiently apart. The tradeoff is that the more trees are spaced apart, the less trees can be planted in a given area, thus reducing the total amount of carbon that can be sequestered (Fig 3.).

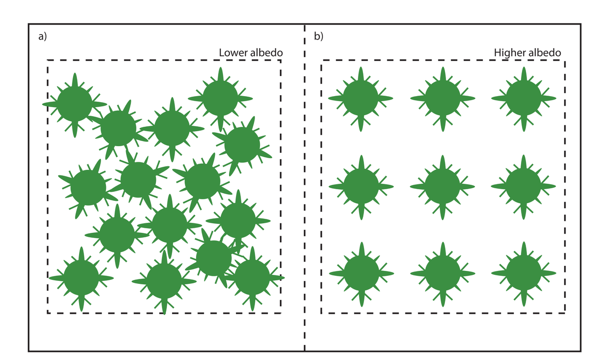

Figure 4. Top-down view of a hypothetical forest. Proper spacing (fraction cover) can minimize the climatic impact from surface reflectivity and promote higher tree productivity, yet this comes at the expense of less carbon being sequestered per unit area.

Forest Age – the age of a forest determines the rate of carbon sequestration with younger forests early in their growth stage (aggrading to maturity) being more effective sequesterers (Fig 5a). In this early growth period the biomass is rapidly being acquired and the climate impact of the albedo effect gets stronger (Fig 5b).The carbon flux in older-growth forests tends to be at a lower steady state as tree productivity equilibrates. The rate of carbon sequestration in old-growth forests can be near zero, thus suggesting that a logical carbon sequestration plan in the high latitudes would be to establish forests with short planting-to-harvest rotation periods of 50-60 years. Growing periods in excess of 50-60 years would have negative consequences because sequestration rates lessen and the albedo effect gets stronger (Fig 5c).

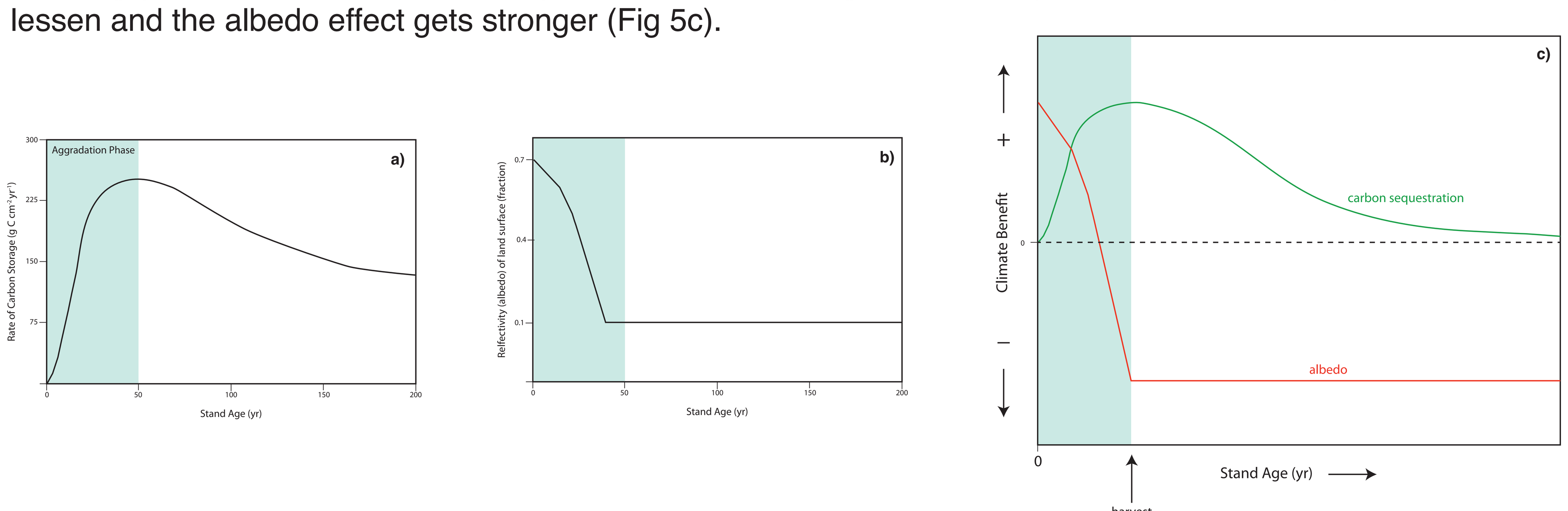

Figure 5. The contribution of forest age on the use of forestation for climate mitigation. a) A typical pattern denoting the rate of carbon storage in northern latitude forests. This pattern is characterized by a rapid increase in carbon storage followed by a gradual decline to an old-growth equilibrium level. b) The reflectivity of a forest as a function of stand age. As biomass is rapidly accumulated early in the stand lifetime, the reflectivity quickly drops before stabilizing. c) The true benefit to the climate system must include the competing effects of carbon sequestration (a benefit) and the albedo impact (a detriment). Early in a forest lifetime, the climate benefit is realized through rapid sequestration and a minimal albedo impact. As the stand ages, however, the climate benefit of the forest reaches a tipping point beyond which the forest provides little climate regulation benefit. At this point, the stand should be harvested and a new forest established. The harvest age depends on the geographic location, climate, soils, and species being planted, so forest management would likely be unique for a specific location. Current research is focused on identifiying the management options for locations across North America.

Forest Species – certain tree species may have high rates of carbon sequestration, but may have less of a biophysical impact relative to species typically considered ideal for carbon sequestration. For example, the boreal black spruce in Canada has traditionally been considered best suited as a species for forest plantations, however, recent research on plantations of hybrid poplar trees suggests that the seasonal albedo impact of poplars, which are a deciduous species, are considerably less than conifers that maintain their needles year-round. In addition, hybrid poplars have been bred to have a shinier leaf surface that may further increase reflectivity during the growing season. Currently, IBIS is being modified to handle representation of hybrid poplars to assess the value of these species for climate mitigation purposes.

Summary

The preliminary results from this study suggest that while carbon sequestration may be a viable approach to mitigating climate change, the biophysical effects (i.e., the surface albedo) must be included in any assessment because they can, in certain cases, dwarf the positive benefits and in fact lead to a warmer, not cooler global climate. The controls on where a forest should be located and for how long it should be grown are complex and require complex models to understand the interactions between the biogeochemical, biophysical, and environmental processes.

Acknowledgments

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