Quantifying the Impact of Albedo-Warming from Afforestation:

A Historical Case Study

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Take Home Message

While afforestation is an effective carbon sequestration strategy, trees are less reflective than a barren landscape and absorb more incoming sunlight. We estimated that afforestation across the Mid Atlantic region of the United States from 1900 to 2000 contributed to an additional carbon dioxide sequestration of 5.70 GtCO_2. At the same time, the decreased amounts of sunlight reflected by the surface resulted in a warming effect equivalent to 1.01 GtCO_2.Therefore, regional afforestation had a net effect of sequestering only 4.69 GtCO_2.

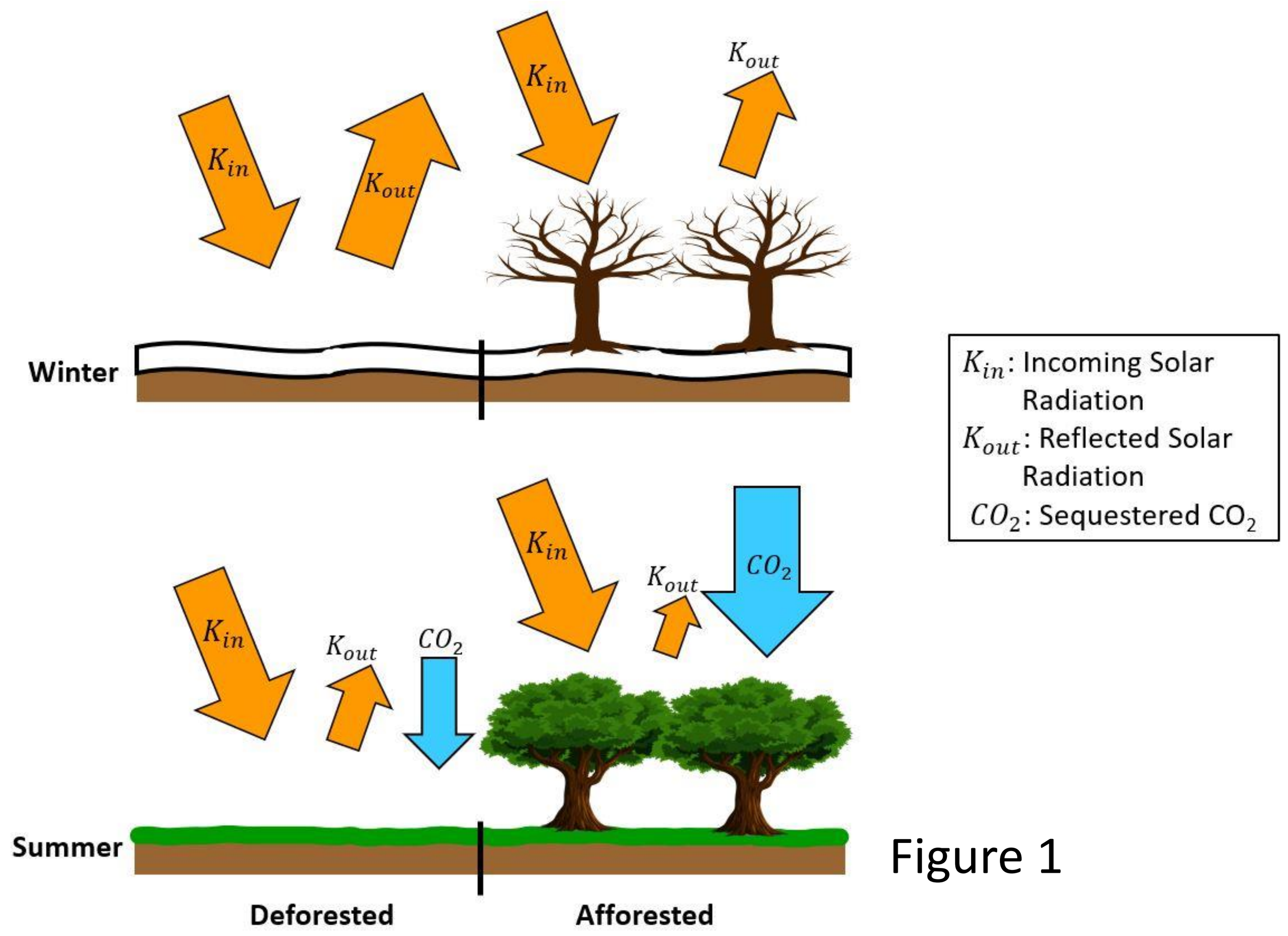

Figure 1

Introduction

In the 19th century, much of the forests throughout the Mid Atlantic U.S. were cut down for lumber, cropland, and pastures. As population and agricultural production moved westwards, many forests have gradually grown back. In this study, we estimate the additional CO_2 sequestered by this new forest area, additional energy absorbed due to the decrease in albedo, and net effect on global warming.

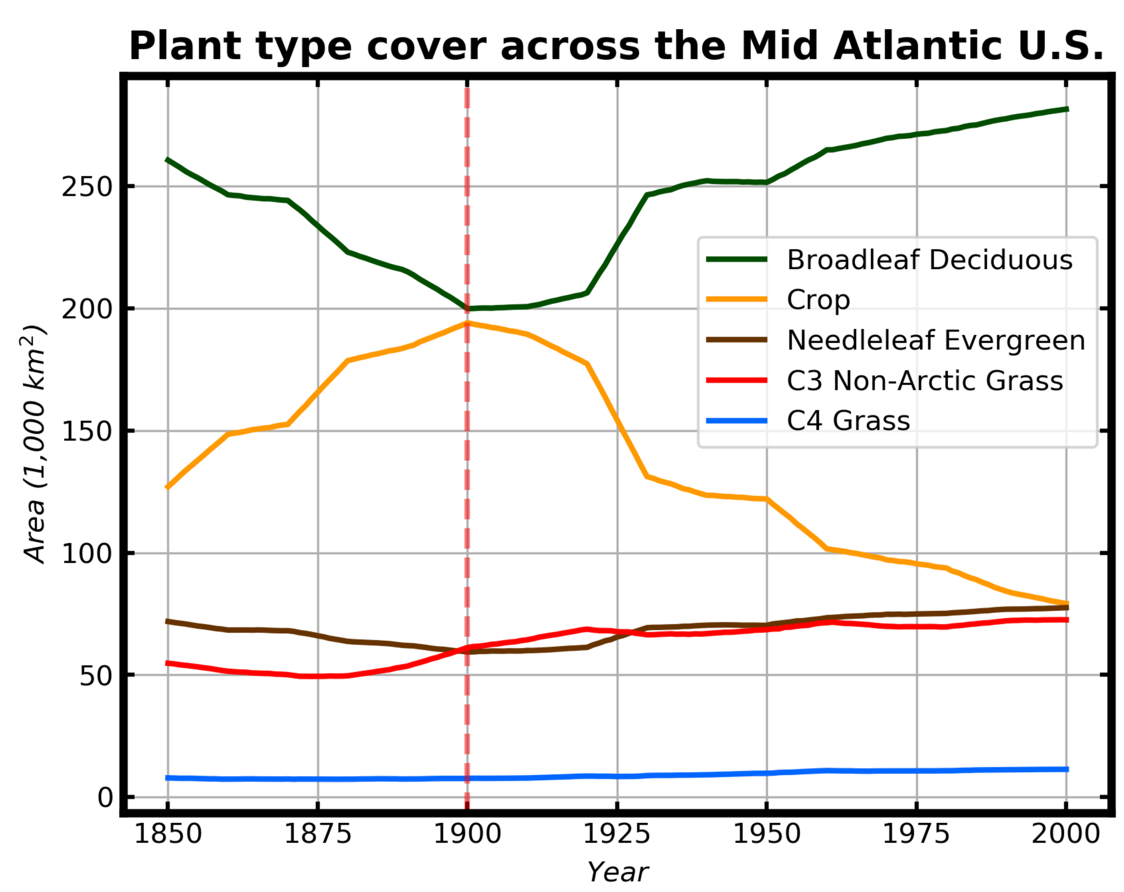

Figure 2

Methods

The year 1900 marked a turning point for vegetation cover across the Mid Atlantic. (Figure 2) Therefore, all calculations of increased CO_2 sequestration and warming promoted by decreased albedo are relative to forested areas in 1900. To calculate area of each plant type, we used data from the National Center for Atmospheric Research (NCAR) Community Land Model simulations from 1850 to 2005[1].

We determined the CO_2 sequestration rate of the forests using a weighted average of the observed maximum carboxylation rate[2] (Vc_{max}) based on the regional forest composition[3]. This Vc_{max} was plugged into a canopy model[4], which allowed us to calculate an annual sequestration rate. (Figure 4)

We estimated changes in albedo from measured albedo values for each plant type in the summer and winter, with and without snow[5,6]. By using historical percentage snow cover data for each latitude and month, we calculated the change in albedo for each month.

We calculated the annual radiative forcing ($RF_{\Delta\alpha}$) from the changes in albedo ($\Delta\alpha$) and monthly insolation[7,8] by latitude ($R_{Sw}^{\downarrow}$)[9].

$$\mathrm{RF}_{\Delta\alpha} = R_{\mathrm{SW}}^{\downarrow} \Delta\alpha_s T_{\mathrm{SW}}^{\uparrow} \quad [\mathrm{Wm}^{-2}]$$

$T_{Sw}^{\uparrow}$: coefficient for the fraction of reflected $R_{Sw}^{\downarrow}$ that makes it to the top of the atmosphere

We calculated the global warming potential by normalizing the warming effect from the albedo to the warming effect of an impulse of CO_2[10]. (*Derived from Bright*[9])

$$\mathrm{GWP}_{\Delta\alpha} = \frac{\int_{t=0}^{\mathrm{TH}} \mathrm{RF}_{\Delta\alpha} \frac{A^{\mathrm{Unit}}}{A^{\mathrm{Earth}}}}{k_{\mathrm{CO_2}} \int_{t=0}^{\mathrm{TH}} y_{\mathrm{CO_2}}(t)} [\mathrm{kgCO_2{-}eq.}]$$

$GWP_{\Delta\alpha}$: global warming potential from change in albedo
TH: Time horizon for which impacts are considered
k_{CO_2}: radiative efficiency of a 1kg increase of CO_2
y_{CO_2}: proportion of an impulse of CO_2 remaining
A^{Unit}: area of land with change in albedo
A^{Unit}: area of Earth

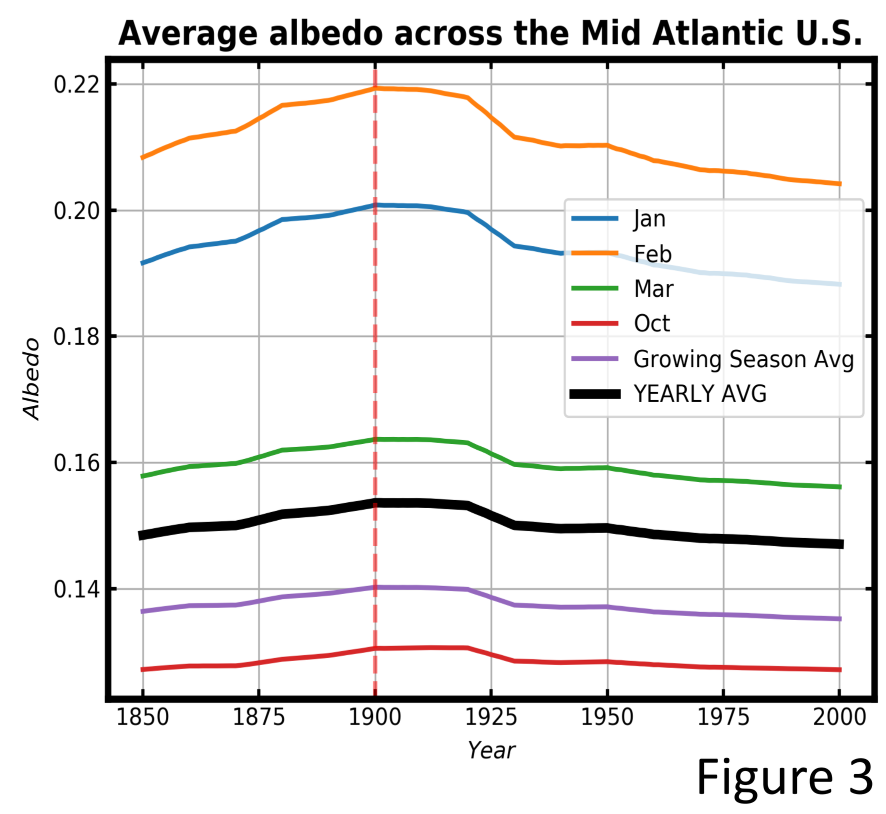

Figure 3

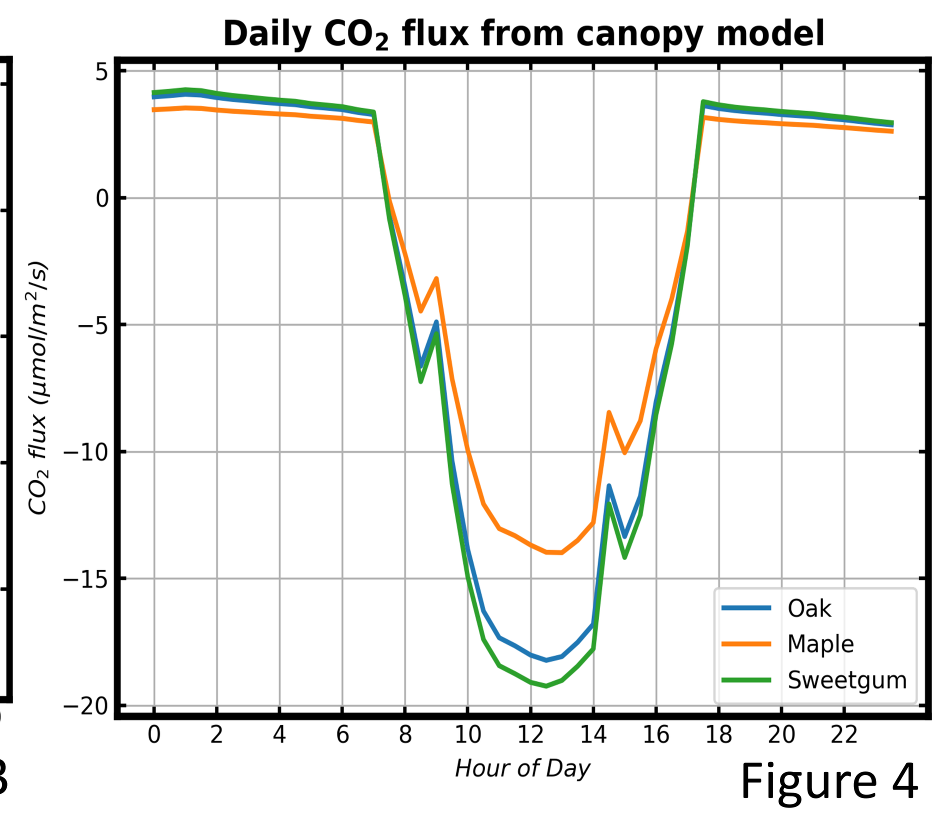

Figure 4

Results

We estimated a 1.7% decrease in average albedo from a peak of 0.154 in 1900 (Figure 3). This decrease caused a warming effect equivalent to 1.01 GtCO_2 between the years 1900 and 2000. Over the same time period, the increase in forest area led to an additional 5.70 GtCO_2 sequestered. The net effect of these results is equivalent to an additional 4.69 GtCO_2 sequestered. This means that the albedo had a 18% "take back" effect on the effectiveness of CO_2 sequestration from afforestation (Figure 5).

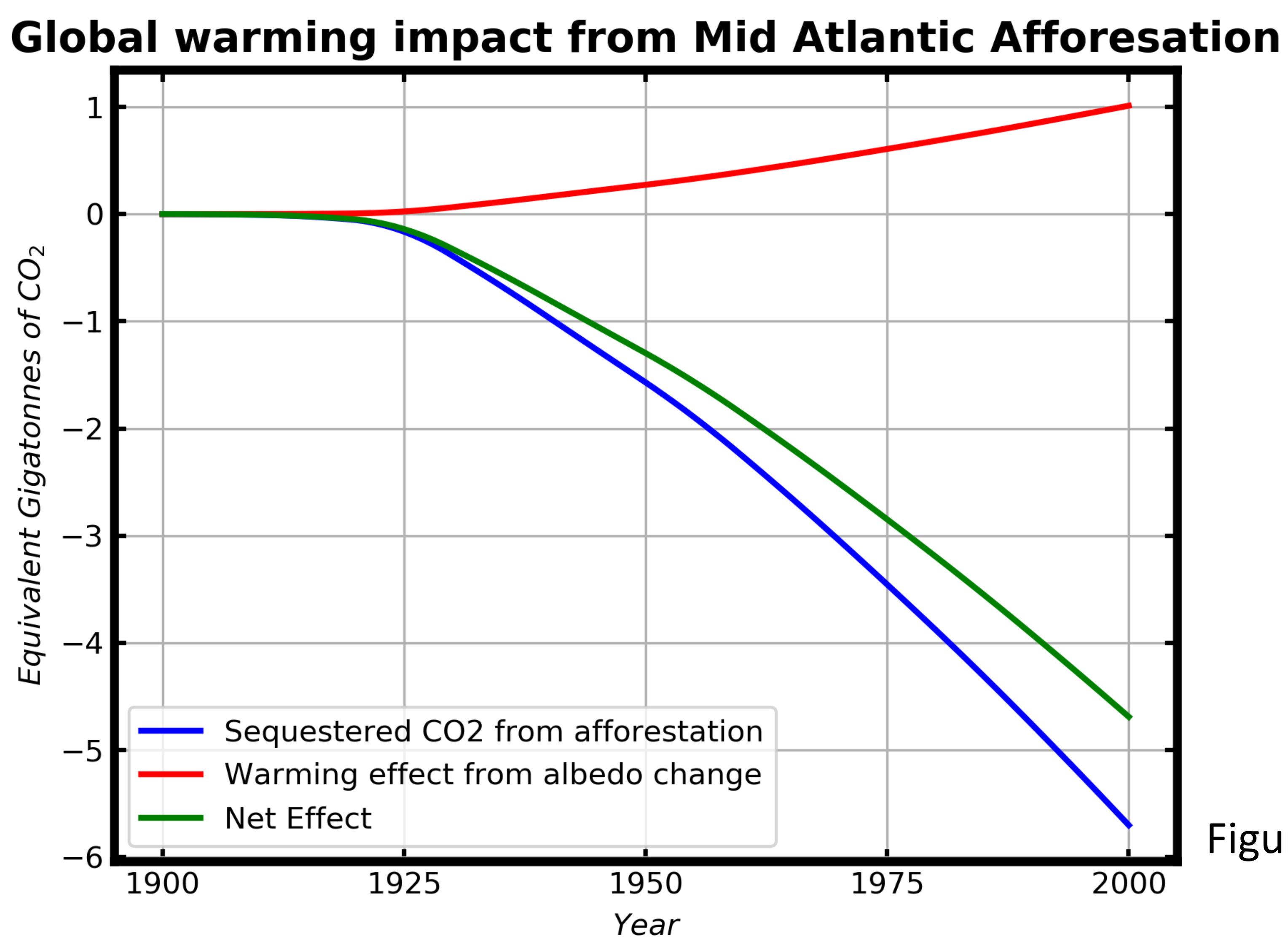

Figure 5

Conclusions

Afforestation has two main effects on the global climate: cooling from CO_2 sequestration, and warming from change in albedo. This study shows that although afforestation has an overall cooling effect on the climate, this effect is somewhat diminished by the warming from albedo, suggesting that global estimates of the cooling potential of afforestation should be reduced.

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