Quantifying the Impact of Albedo-Warming from Afforestation:

Looking to the Future

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Introduction

Afforestation is a cost-effective carbon sequestration strategy, which Project Drawdown projects can capture 18.1-41.6 Gt of CO2 by 2050. However, afforestation also darkens the surface of earth, decreasing its albedo and leading to a direct radiative warming effect. The magnitude of this effect varies spatially and is primarily dependent on incoming solar radiation (a function of cloud cover and latitude) and monthly snow cover. Here we model the radiative impact of a hypothetical 1-hectare transition from field to forest across the earth's surface, in an effort to constrain estimates of afforestation's global cooling potential.

Data/Methods: Albedo & Carbon Equivalence

Using 10 years of data from NASA's CERES project[1,2] and the National Snow and Ice Data Center[3], we constructed monthly maps representing average climatic conditions for incoming solar radiation and snow cover percentage. We surveyed reported albedos for forests and grasslands/croplands with and without snow on the ground[4], and then combined all this data into an instantaneous radiative forcing ($RF_{\Delta\alpha}$) for each month using the equation below *(derived from Bright, 2015)*[5].

$$\mathrm{RF}_{\Delta\alpha} = R^{\downarrow}_{\mathrm{SW}} \Delta\alpha_s T^{\uparrow}_{\mathrm{SW}}$$

$$\mathrm{RF}_{\Delta\alpha} = R^{\downarrow}_{sw}\left[(1-\varphi)\left(\alpha_{grass} - \alpha_{aff}\right) + \varphi\left(\alpha_{\varphi grass} - \alpha_{\varphi aff}\right)\right]T^{\uparrow}_{sw}$$

$\varphi = percent\ snow\ cover,$
$RF^{\downarrow}_{sw} = incoming\ solar\ radiation,$
$T^{\uparrow}_{sw} = the\ percentage\ of\ reflected\ solar\ radiation\ that\ leaves\ the\ atmosphere\ (assumed$ as 0.85)

We aggregated these monthly maps into a yearly average. Then we converted the yearly instantaneous ($RF_{\Delta\alpha}$) values into their equivalent global warming potential using the equation below *(derived from Bright, 2015)*[5]…

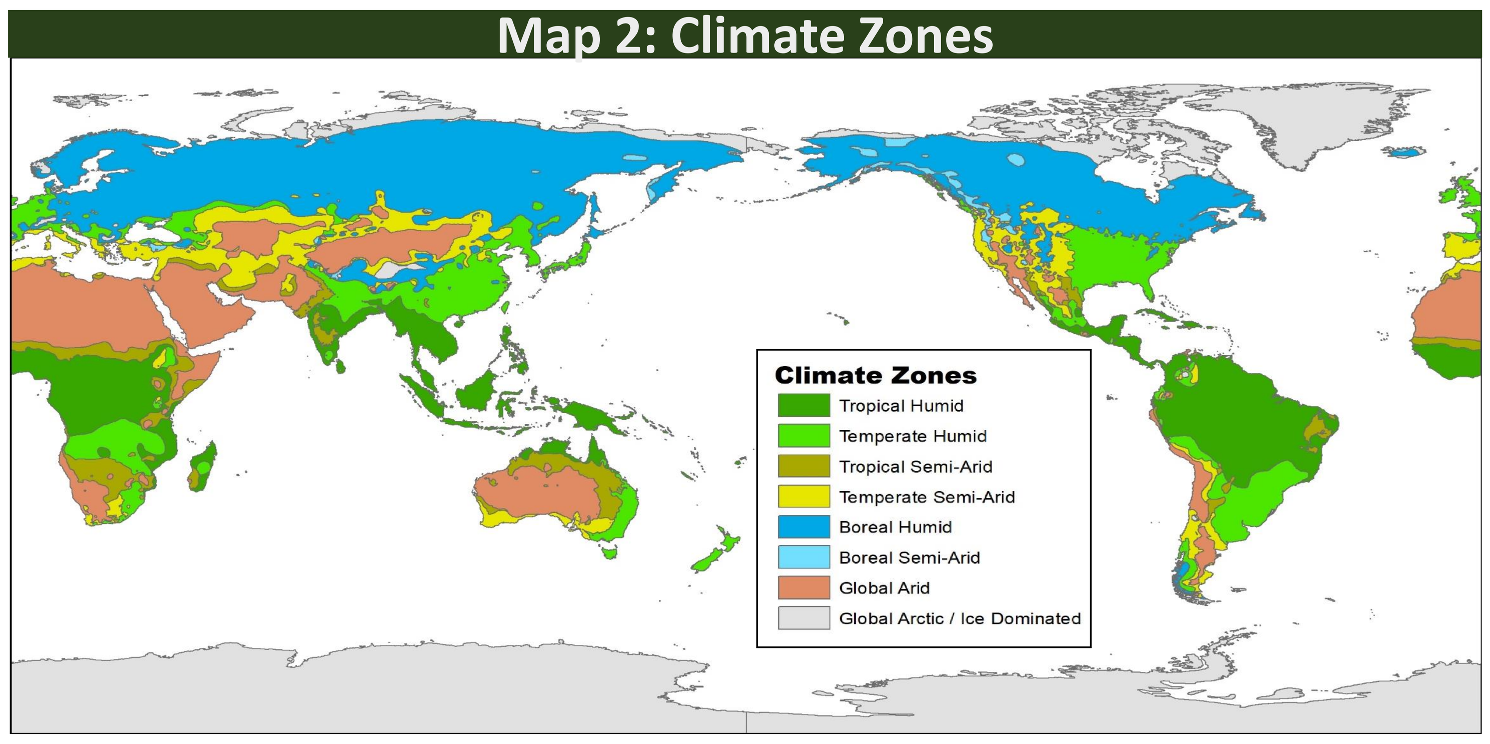
$$\mathrm{GWP}_{\Delta\alpha} = \frac{\int_{t=0}^{\mathrm{TH}} \mathrm{RF}_{\Delta\alpha} \frac{A^{\mathrm{Unit}}}{A^{\mathrm{Earth}}}}{k_{\mathrm{CO_2}} \int_{t=0}^{\mathrm{TH}} y_{\mathrm{CO_2}}(t)} \left[\mathrm{kgCO_2{-}eq.}\right]$$

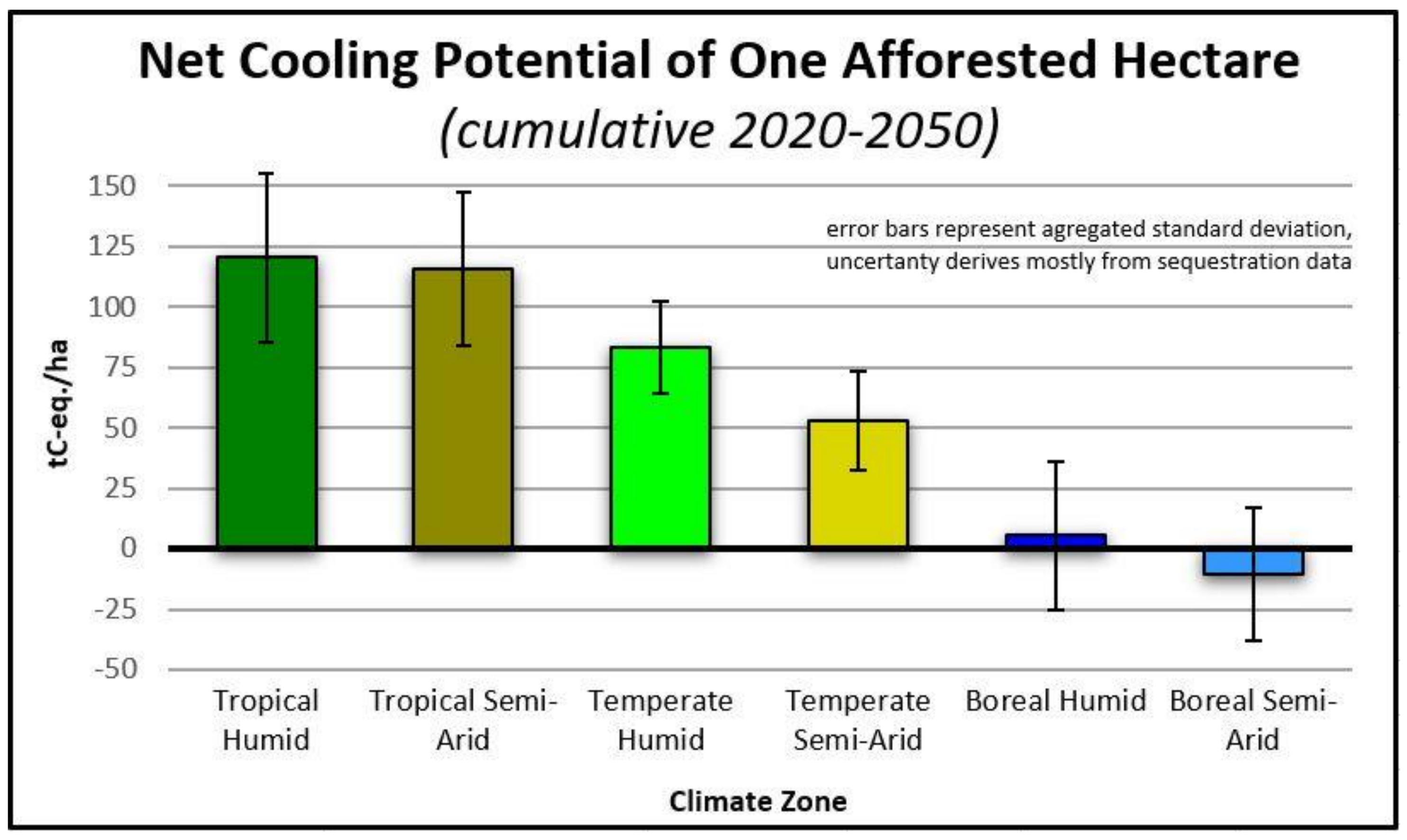
$TH = time\ horizon\ (years)$
$k_{CO2} = the\ abloslute\ GWP\ of\ 1\ kg\ of\ CO2,$
$yCO2 = the\ impulse\ response\ function\ of\ CO2\ over\ time$

…given the following assumptions:

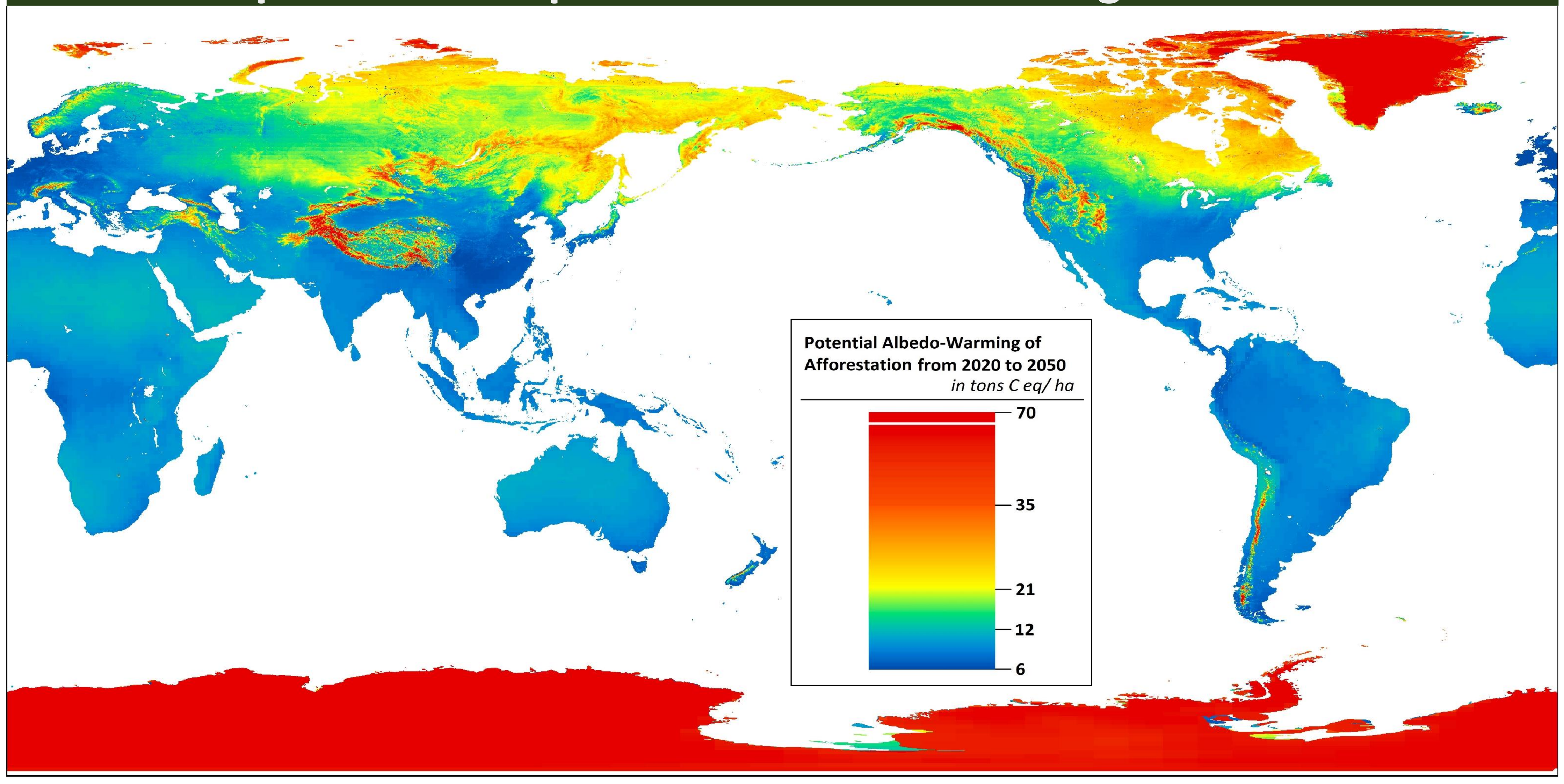
- Albedo changes act only from 2020-2050
- Field albedos transition to forest albedos linearly over the first 8 years of forest growth
- Atmospheric CO2 levels of 415 parts per million (ppm)
- The hypothetical impulse of CO2 (denominator) occurs in 2020 and acts until 2100

Map 2: Climate Zones





Map 1: Carbon Equivalence of Albedo Change 2020-2050



Data/Methods: Sequestration & Climate Zones

Using data from Oak Ridge National Laboratory[6,7], we produced a map of broad climate zones based on with Project Drawdown's aggregation of Köppen-Geiger classes (altered slightly to increase accuracy).

Tropical Humid	Tropical Semi-Arid	Temperate Humid	Temperate Semi-Arid	Boreal Humid	Boreal Semi-Arid	Global Arid	Global Arctic / Ice
A	Bsh	Cf, Cw, Dfa, Dwa	Bsk, Cs, Dsa	Cfc, Dfb-d Dwb-d	Ds	Bw	E

We overlaid the two maps and queried the data from map 1 to output averages for albedo-warming carbon eq. in each climate zone. To compare the magnitude of local albedo warming with that of local drawdown cooling, we surveyed the literature for existing meta-analyses of yearly sequestration rates across forests in each climate zone. Two high-quality surveys were identified[8,9], but neither shared Project Drawdown's exact definitions of each climate zone. We averaged their reported rates and data variances to smooth out this spatial misalignment. Dividing yearly C-eq. from albedo change by yearly C sequestration produced "takeback" rates that represent the percentage of carbon sequestration negated by albedo warming. Subtracting cumulative albedo C-eq. from cumulative C sequestration produced net cooling potentials over the 2020-2050 study period.

Results

Cooling and Warming Effects by Climate Zone *(reported per year)*

Climate Zone	**Avg. Sequestration** tC/ha/yr	*Std. Dev. of Sequestration*	**Avg. Albedo-Warming** tCeq/ha/yr	*Std. Dev. of Albedo Warming*	**"Takeback" Rate**
Tropical Humid	**4.36**	*1.17*	**0.340**	*0.037*	**7.8%**
Tropical Semi-Arid	**4.24**	*1.05*	**0.386**	*0.048*	**9.1%**
Temperate Humid	**3.13**	*0.614*	**0.353**	*0.160*	**11.3%**
Temperate Semi-Arid	**2.24**	*0.644*	**0.474**	*0.248*	**21.1%**
Boreal Humid	**0.83**	*1.01*	**0.644**	*0.190*	**78.0%**
Boreal Semi-Arid	**0.37**	*0.867*	**0.715**	*0.285*	**193%**

Conclusions & Recommendations

- Our results support the conclusion that boreal afforestation *(both high-latitude and high-altitude)* is not an effective global cooling strategy, and furthermore that it is counterproductive where moisture is limited. This concurs with the results of related Earth system model experiments[10,11]. We therefore recommend that Project Drawdown exclude boreal regions from its calculation of the global land area applicable to afforestation.
- Over the next 30 years, we estimate that 7-21% of the cooling effect of CO2 sequestration from tropical and temperate afforestation will be negated by albedo-warming. Project Drawdown should apply our zonal "takeback" percentages as coefficients in their carbon accounting to include the "virtual emissions" of albedo change due to afforestation.

Caveats

- These estimations assume the last 10 years of snowfall data to be reasonably representative of the spatial patterns in snowfall over the next 30 years. Global warming significantly undermines the validity of this assumption. The magnitude of afforestation's albedo warming in the high latitudes will be dynamically impacted by the evolving climate. The exercise also makes similar assumptions about cloud cover (implicit in the downward SW flux data), which could be altered in the future by global warming-derived changes in atmospheric circulation, or directly by the increased evapotranspiration that would result from global-scale afforestation. Future investigations should strive to project changing snow and cloud cover patterns over the studied time horizon.
- Inconsistencies in the spatial definitions of each climate zone also make these results preliminary. Future studies should directly survey carbon sequestration measurements and assign them to internally consistent climate zones based on their coordinate locations.
- Standard deviations may not reflect gausian distributions; elevation skews RF

Key References

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