*forests*

*Article*

# Community Earth System Model Simulations Reveal the Relative Importance of Afforestation and Forest Management to Surface Temperature in Eastern North America

**Benjamin J. Ahlswede * and R. Quinn Thomas**

Department of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg, VA 24061, USA; rqthomas@vt.edu

* Correspondence: bswede@vt.edu

Received: 1 November 2017; Accepted: 2 December 2017; Published: 13 December 2017

**Abstract:** Afforestation changes the land surface energy balance, though the effects on climate in temperate regions is uncertain, particularly the changes associated with forest management. In this study, we used idealized Community Earth System Model simulations to assess the influence of afforestation and afforestation management in eastern North America on climate via changes in the biophysics of the land surface. Afforestation using broadleaf deciduous trees maintained at high leaf area index (LAI) in the southern part of the study region provided the greatest climate benefit by cooling summer surface air temperatures ($T_{sa}$). In contrast, the greatest warming occurred in the northern extent of the study region when afforesting with needleleaf evergreen trees maintained at high LAI. Forest management had an equal or greater influence on $T_{sa}$ than the overall decision to afforest land in the southern extent of the region. Afforestation had a greater influence on $T_{sa}$ than forest management in the northern extent. Integrating our results, focused on biophysical processes, with other research quantifying carbon cycle sensitivity to management can help guide the use of temperate afforestation to optimize climate benefits. Further, our results highlight the potential importance of including forest management in simulations of past and future climate.

**Keywords:** afforestation; albedo; biophysics; earth system modeling; forest-climate interactions; surface air temperature; temperate forests

## 1. Introduction

Forests influence local, regional, and global climate by regulating the planetary energy balance [1]. By absorbing carbon dioxide ($CO_2$) from the atmosphere, forests cool surface temperatures. However, forests also alter the biophysics of the land surface by reflecting energy (albedo) and by regulating the movement of energy from the land surface into the atmosphere. Quantifying the net influence of these biogeochemical and biophysical processes on climate is important for determining the climate benefits of afforestation projects to mitigate climate change [2]. Furthermore, quantifying how biogeochemical and biophysical processes are sensitive to forest management decisions, such as plant species selection and actions to increase productivity, can help maximize climate mitigation. While biogeochemical processes (i.e., carbon uptake and storage) are widely studied and exert a cooling influence on climate in an aggrading forest, the magnitude and spatial patterns of the biophysical effects of afforestation on climate are less well understood [3].

One key factor that potentially influences the climate mitigation capacity of an afforestation project is the location of afforestation, particularly the latitude [1]. There is strong evidence that tropical and boreal forests have very different biophysical effects on climate. In boreal regions, afforestation may have a warming effect on local and regional temperatures despite the additional removal of carbon from the atmosphere [4], by masking bright snow with dark tree canopies, decreasing albedo, and increasing the energy absorbed by the land surface. In contrast, forests in tropical regions have a cooling effect on the land surface temperature because high transpiration rates increase latent heat fluxes enough to outweigh the moderate decrease in albedo [5,6]. Temperate forests cover a range of environmental conditions, including boreal-like regions with winter snow cover and tropical-like regions with warm-moist climates, thus causing the influence of afforestation on temperature to vary across the temperate region [7]. Therefore, it is important to quantify how the influence of afforestation on temperature varies across latitude and season in the temperate region.

The decision of what tree type to plant in an afforestation project is a second factor that may influence climate mitigation capacity [7]. Broadleaf trees tend to have higher annual mean albedo than evergreen trees [7,8]. In addition, studies have shown that broadleaf trees in midsummer have nearly twice the capacity to evaporate water than do evergreen trees [9]. Remote sensing measurements of temperate ecosystems have found that broadleaf trees tend to have cooler surface temperatures than grass and cropland land-cover types, while evergreen trees have warmer surface temperatures [7]. Overall, these data suggest that management decisions about what tree type (e.g., plant functional type or PFT) to plant may be similar to, or more important than the decision to establish an afforestation project [7,10].

A third factor that may influence the climate mitigation capacity associated with an afforestation project is the intensity of forest management, as temperate forests are among the most intensely managed forest systems in the world [11]. Forest management generally aims to increase productivity, and more intensely-managed stands can have higher leaf area index (LAI) than unmanaged stands [12,13]. Increasing LAI can decrease albedo, because greater leaf area covers the more reflective soil and snow [14]. Furthermore, increasing LAI can also increase canopy conductance and latent heat flux [14]. The net biophysical effect on climate in response to forest management remains largely unknown, but may potentially affect climate as strongly as the overall decision to afforest [10].

Isolating the relative influence of location, tree species, and management intensity on afforestation's effect on climate and the biophysical mechanisms driving the climate response is methodologically challenging. Remote sensing has been used to compare satellite-derived estimates of air temperature between pixels of different land-cover and forest types [6,15,16]. However, comparing the relative influence of location, species, and intensity of management requires detectable differences in these factors within a relatively small spatial domain in which background climate is assumed to be homogeneous. Furthermore, while remote sensing estimates of temperature can highlight differences between vegetation types, additional observations are required to parse the mechanisms controlling the differences in temperature among albedo, latent heat, and sensible heat fluxes. Eddy-covariance towers, particularly co-located multi-tower arrays, have been used to compare the temperature among land-cover and forest types and measure differences in the key biophysical processes [7,10]. However, the spatial coverage of paired eddy-covariance towers that isolate tree type and management intensity is limited.

In contrast to empirical methods, coupled atmospheric-land surface models and Earth System Models (ESMs) can use simulations with different land-cover inputs to develop the contrasts required to isolate location (by simulating afforestation in different pixels of the model), tree types, and management as a driver of surface temperature. Simulation studies also allow for the assessment of temperature changes that include the final outcome of the interactions and feedback between the surface and atmosphere. Earth System Model modeling is a key tool for the development of a more refined understanding of the drivers governing the role of afforestation in the climate system [17,18].

Here we use a coupled atmosphere-land surface model (Community Earth System Model; CESM) to examine the influence of afforestation in eastern North America on surface air temperatures and explicitly evaluate the importance of the location of the project, the tree type used in the project (evergreen needleleaf vs. broadleaf deciduous), and the management intensity (represented by a change in LAI). We evaluate the hypothesis that the influence of land-cover change (i.e., the overall decision to afforest and convert grassland to forest, as defined in Reference [10]) is similar to the influence of forest management (i.e., a change in tree type or LAI, as defined in Reference [10]) on land surface temperatures.

## 2. Materials and Methods

Simulations were performed using the CESM 1.2.0; a state-of-the-art fully coupled Earth system model managed by the National Center for Atmospheric Research [19]. The CESM includes several sub-models that separately simulate the atmosphere, land-surface, ocean, sea-ice, rivers, glaciers, and waves. The configuration we used included the Community Land Model (CLM) version 4.5 [20], the Community Atmosphere Model version 5.0 (CAM), the Sea-Ice model, and a prescribed data ocean (i.e., fixed sea-surface temperatures). CLM simulates the exchange of energy, water, momentum, and carbon between the land surface and the atmosphere using process-based models of surface energy balance, radiative transfer through the canopy, hydrology, soil physics, and vegetation physiology. CAM uses the output of energy, water, and momentum from the CLM and the ocean models as inputs to simulate atmospheric dynamics, including surface air temperature. Within the CLM, we used the prescribed phenology routine, which prescribes the vegetation distribution and leaf area index (LAI) from a gridded input file. The prescribed phenology configuration simulates photosynthesis and transpiration but does not add or remove carbon from the atmosphere, which was appropriate given our focus on changes in the biophysics (i.e., energy and water) associated with afforestation (we explore the implications of this configuration on our conclusion in the discussion section). In the CLM 4.5, vegetation is divided into 16 broad plant functional types (PFT) that include the three focal PFTs used in this study: temperate C3 grasses (Grass), temperate broadleaf deciduous trees (BDT), and temperate needleleaf evergreen trees (NET). Each plant type has physiological parameters that govern photosynthesis (based on the Farquhar photosynthesis model), transpiration (based on the Ball-Berry conductance model), energy balance (e.g., reflectance, transmittances, and leaf angles), height of vegetation, and rooting distributions [20]. In the default CLM 4.5 parameterization used here, the tree PFTs are parameterized to be taller with stems and leaves that have lower reflectance than the C3 grass. Grass has higher photosynthetic parameters and similar stomatal conductance parameters to BDT and NET. A full description of the PFTs and the specific set of parameter values used is located in the CLM 4.5 technical description [20]. Overall, the CESM used gridded PFT distributions, gridded PFT LAI, and PFT parameters as inputs to calculate land-surface fluxes and surface air temperatures via the processes in the CLM and CAM sub-models.

To assess the relative contribution of location, tree type, and magnitude of LAI on temperature, we ran five global simulations that differed in the prescribed plant type and LAI (Table 1). We selected grid-cells in eastern North America (Figure 1) in which both NET and BDT had a yearly maximum LAI greater than 2 in the default CLM 4.5 land-surface data [20]. We manipulated the PFT and LAI of these cells to create five land-surface descriptions that were used as inputs to the CLM. Each set had PFT distributions of either 100% NET, BDT, or Grass in every selected grid-cell. Grid-cells outside of the focal region (Figure 1) retained their default PFT and LAI distributions. We used the differences in output from these simulations, as described below, to assess the influence of afforestation (Grass to NET or BDT transition) and forest management (NET to BDT transition or low to high LAI transition) on surface air temperature and energy fluxes.

**Table 1.** The five simulations run using the Community Earth System Model 1.2.0.

| Simulation Name | Plant Functional Type | Maximum Annual Leaf Area Index (LAI) |
|---|---|---|
| NET-LAI4 | 100% Needleleaf Evergreen Tree (NET) | 4 |
| BDT-LAI4 | 100% Broadleaf Deciduous Tree (BDT) | 4 |
| NET-LAI2 | 100% NET | 2 |
| BDT-LAI2 | 100% BDT | 2 |
| Grass | C3 Grass | 3 |

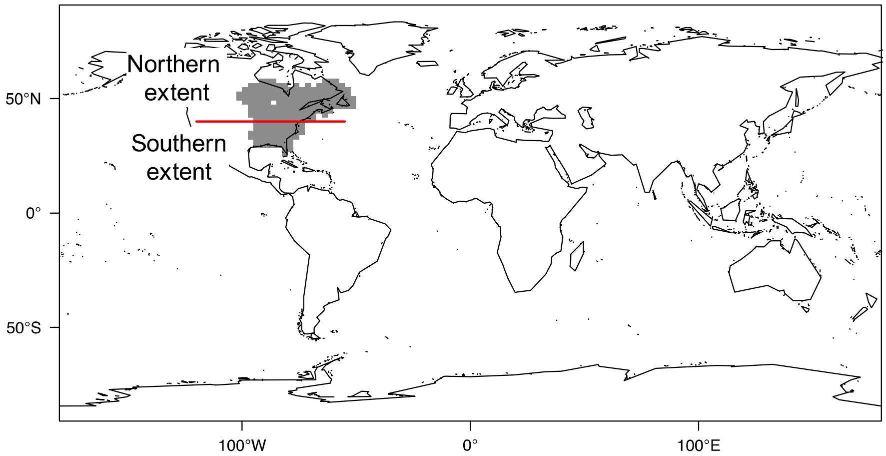

**Figure 1.** Global simulations were run with where the vegetation in eastern North America (gray region) was modified to represent 100% coverage by each of the plant types in Table 1. We focused our analysis on the modified grid-cells and further divided the analysis into the northern extent (gray area above 40° N) and the southern extent (gray area below 40° N).

To ensure that differences between tree types were not due to any uncontrolled differences in LAI, we standardized the LAI level across the region by modifying the input data that defines monthly LAI for each grid-cell. Maximum grass LAI was set to three. BDT and NET had two sets of simulations: high LAI, where maximum summer LAI equaled 4, and low LAI, where maximum summer LAI equaled 2. We chose the lower value of LAI because we assumed an afforestation project would not occur if the climate was unable to support an LAI greater than 2. We chose the upper value of LAI because albedo changes associated with an additional increase in LAI are similar for LAI values above 4 [14]. We preserved the seasonal cycle of LAI by scaling the remaining months by the same factor used to scale the peak month to our standardized levels. In addition, peak stem area index (SAI) was scaled proportionally to the change in peak LAI for that grass or tree type and grid-cell and non-peak SAI was scaled in the same way as non-peak LAI.

Each simulation listed in Table 1 was run from a common initial state but with differing land surface inputs that reflect the tree type and LAI distributions specific to the simulation. Simulations were run on a 1.9° × 2.5° horizontal resolution for 30 years to allow the system to reach a dynamic equilibrium. While the simulations predicted climate over the entire globe, we focused our analysis on the grid-cells highlighted in Figure 1 and on the final 20 years of each simulation, discarding the first 10 years of simulation data as the model spin-up necessary to ensure that the climate has stabilized with the modified land surface (as commonly done in simulations focused on equilibrium differences in climate; [17,18]). We analyzed the responses of the 2-m air temperature variable simulated by the CESM because it is commonly reported in other modeling studies (e.g., [18]) and from meteorological stations in differing land-cover types [21]. In addition, we examined differences in albedo, shortwave radiation that reaches the land surface (i.e., incoming solar radiation not reflected by clouds), latent heat flux, and sensible heat flux to analyze the explanatory value of these biophysical processes. To calculate the influence of afforestation on temperature, we subtracted the Grass simulation from the NET or BDT simulations with the two levels of LAI. We focused our analysis on the temperature differences at the seasonal time-scale (summer: June, July, and August; winter: December, January, and February). To compare the influence of land-cover change (afforestation) to the influence of forest management (tree type selection and LAI level) and location (northern vs. southern extent of the focal region) on temperature change, we used the afforestation with BDT-LAI 4 as the baseline land-cover change and evaluated deviation from the baseline. The influence of tree type selection on temperature change was calculated as the difference between the BDT-LAI 4 and NET-LAI 4 simulations. The influence of management intensity (low vs. high LAI) on temperature was calculated as the difference between the BDT-LAI 4 and BDT-LAI 2 simulations. The combined influence of tree type selection and management intensity was the difference between the BDT-LAI 4 and NET-LAI 2 simulations. To highlight the importance of location, we report the changes in temperature for the northern extent of the focal region (all grid-cells above 40° N latitude) and the southern extent (all grid-cells below 40° N latitude) separately. As commonly performed when comparing equilibrium climate simulations [18], we treated the seasonal means from each year of the simulation as a sample from the underlying distribution and assessed statistical differences between simulations for each grid-cell by using a $t$-test and $p$-level of 0.05.

## 3. Results

The change in surface air temperature associated with the decision to afforest from grassland to forest in eastern North America ranged from $-1.63$ to 7.92 °C for individual grid-cells, depending on the season, location, tree type, and LAI level (Figure 2). A majority of the grid-cells, especially in summer months in the southern extent and in both seasons in the northern extent, exhibited significant changes in temperature in response to afforestation (Figure 2). The greatest warming occurred during the winter in the northern extent when afforesting with the NET tree type managed to have a high LAI (LAI = 4). In this case, afforestation increased surface temperatures by 4.73 °C when averaged across grid-cells in the northern extent. In contrast, the greatest cooling occurred in the southern extent during summer months when afforesting with the BDT tree type managed to have a high LAI (4); afforestation decreased surface temperatures by 0.22 °C averaged across the southern extent. Larger decreases in temperature than 0.22 °C were simulated in the winter months in the southern extent when afforesting with BDT. However, grid-cells in the southern extent in the winter had relatively high inter-annual variability, resulting in a lack of statistical significance in the change in surface air temperature between the grass and tree type simulations (Figure 2).

Focusing on our baseline afforestation simulation (BDT-LAI 4-Grass), afforestation decreased albedo across the region, particularly in the northern extent during winter months where taller darker trees masked bright snow more than the shorter grass (Figure 3). In the winter, the decrease in albedo resulted in an increase in solar radiation absorbed by the land surface. This spatial pattern in albedo change during the winter was similar to the spatial pattern in temperature change (Figure 2). In the summer, the decrease in albedo was smaller than in the winter and consistent across the region (Figure 3). Despite the spatial consistency in the albedo change, there was still a difference in temperature change in response to afforestation between the northern and southern extents. The temperature change did not parallel changes in sensible heat flux, which increased consistently with afforestation across eastern North America, and latent heat, which showed small and non-spatially coherent changes with afforestation (Figure 3). Instead, the temperature change paralleled a gradient in the amount of solar energy that reached the land surface, in which afforestation increased the amount of solar radiation that passed through the atmosphere more in the northern than southern extent (Figure 3).

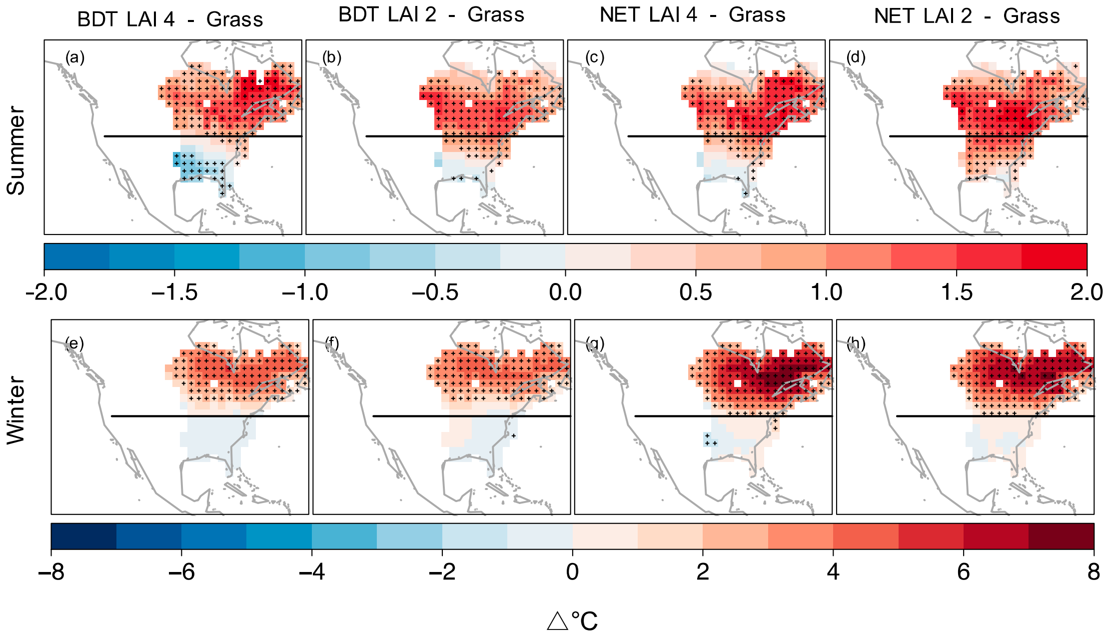

**Figure 2.** The change in surface air temperature due to afforestation in eastern North America for different tree types and levels of LAI. The summer (**a**–**d**; June, July, and August) and winter (**e**–**h**; December, January, and February) season means are shown. The stipples denote statistical significance between simulations at the $p < 0.05$ level. The horizontal line denotes the northern and southern extents used in the analysis.

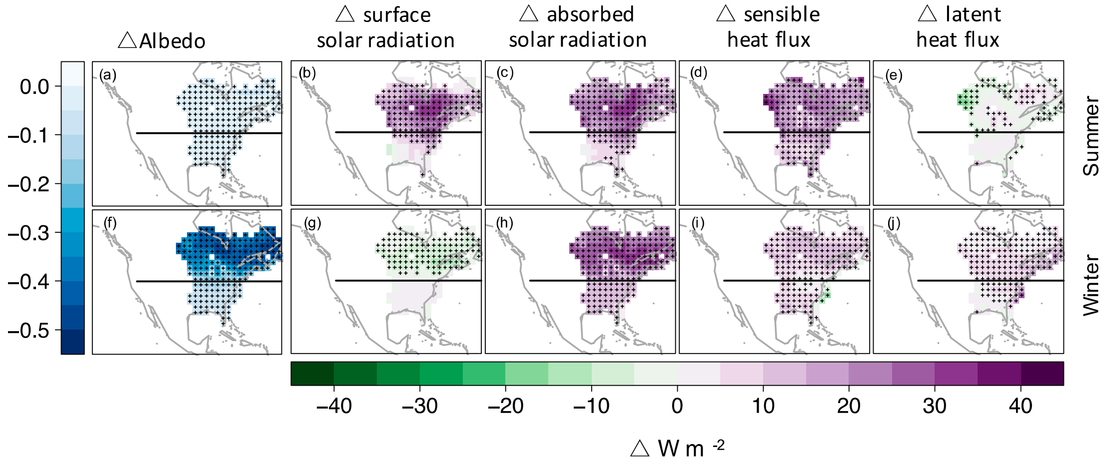

**Figure 3.** The influence of afforestation in eastern North American on albedo (**a**,**f**), solar radiation passing through the atmosphere to reach the land surface (**b**,**g**), solar radiation absorbed by the land surface (**c**,**h**), sensible heat exchanged between the land surface and the atmosphere (**d**,**i**), and latent heat exchange between the land surface and the atmosphere (**e**,**j**). Summer and winter months are shown for afforestation using a broadleaf deciduous tree type with an LAI of 4. The stipples denote statistical significance between simulations at the $p < 0.05$ level. The horizontal line denotes the northern and southern extents used in the analysis. Albedo is the ratio of outgoing to incoming solar radiation. Solar radiation, sensible heat flux, and latent heat flux are expressed as the change in energy flux, defined as a watt $m^{-2}$ (equivalent to a Joule $m^{-2}$ $s^{-1}$).

In the southern extent of the region, the temperature change associated with forest management change (tree type and LAI) was larger than that caused by a land-cover change (afforestation), particularly in the summer (Figure 4; Table 2). In the summer, decreasing LAI or switching to a

NET tree type both increased temperatures by >0.52 °C compared to the baseline change of −0.22 °C (Figure 4; Table 2). In the winter, the same pattern holds, but the changes within the grid-cells were not significantly different from zero (Figure 4).

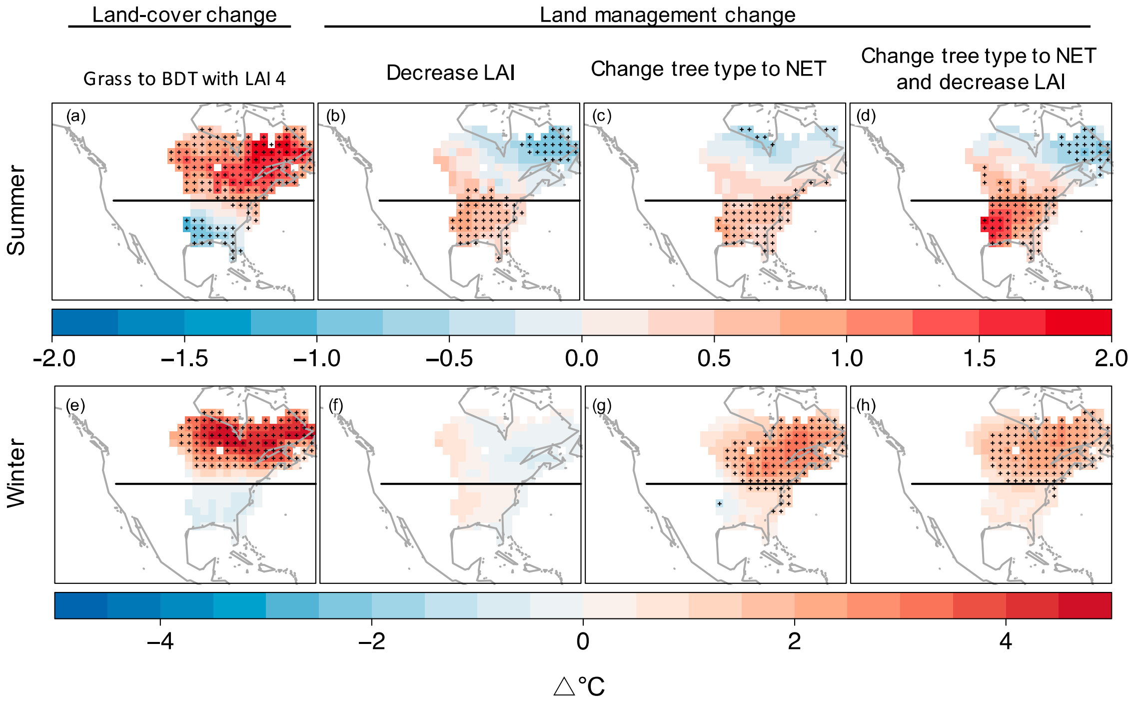

**Figure 4.** An analysis of the simulations in Figure 3 to compare the influence of land-cover change (**a**,**e**: defined as afforestation from grass to broadleaf deciduous tree with an LAI of 4) to the influence of land management (**b**–**d**,**f**–**h**: defined as change in tree type or a decrease in LAI from 4 to 2) on seasonal land surface temperatures. The stipples denote statistical significance between simulations at the $p < 0.05$ level. The horizontal line denotes the northern and southern extents used in the analysis.

**Table 2.** The influence of land-cover and land management change on surface air temperatures. All values are in °C.

| Season | Location | Land-Cover Change (Afforestation with BDT-LAI4) | Land Management Change | Temperature Change Relative to Land-Cover Change | Proportional Difference |
|---|---|---|---|---|---|
| Summer | North | 1.16 | decrease leaf area index(LAI) | −0.11 * | −0.09 * |
| | | | tree type | 0.12 * | 0.10 * |
| | | | tree type and decrease LAI | 0.04 * | 0.03 * |
| | South | −0.22 | decrease LAI | 0.54 | −2.45 |
| | | | tree type | 0.52 | −2.36 |
| | | | tree type and decrease LAI | 0.98 | −4.45 |
| | (N–S) | 1.83 | | | |
| Winter | North | 2.83 | decrease LAI | 0.04 * | 0.01 * |
| | | | tree type | 1.9 | 0.67 |
| | | | tree type and decrease LAI | 1.75 | 0.62 |
| | South | −0.45 * | decrease LAI | 0.22 * | −0.49 * |
| | | | tree type | 0.55 * | −1.22 * |
| | | | tree type and decrease LAI | 0.59 * | −1.31 * |
| | (N–S) | 3.28 | | | |

* A majority of grid-cells did not have differences that were statistically different than zero (see Figure 4).

In the northern extent of the region, the temperature change associated with land-cover change (afforestation) was larger than that caused by forest management change (tree type and LAI) (Figure 4; Table 2). In the winter, changing the tree type from BDT to NET increased temperatures by 1.9 °C, a value 67% as large as the temperature change associated with afforestation. In the summer, the changes associated with forest management were less than 10% of the changes associated with afforestation and a majority of grid-cells had differences that were not significantly different from zero.

## 4. Discussion

The overall goal of this study was to quantify the relative influence of three factors on the climate benefits of a temperate afforestation project: location of project, tree functional type used in afforestation, and management intensity of the forest. Previous studies that have modeled the biophysical influences of temperate afforestation on climate have focused on only one tree type (e.g., loblolly pine; [18]) or multiple tree types simultaneously [17], thus not isolating the individual contributions of the two dominant tree types (needleleaf evergreen and broadleaf deciduous). Furthermore, previous studies have allowed LAI to vary across space and between tree types, potentially confounding the influences of tree type and location on temperature change.

Here, our simulations used a simplified coupled land-atmosphere model experiment with 100% coverage of the focal plant type to isolate the individual effects of location, tree type, and forest management. Therefore, while we are unable to quantify the temperature change associated with a specific afforestation project, our results provide general guidance: in the CESM, afforestation using deciduous trees in the southern part of eastern North America and maintaining high LAI provides the greatest climate benefit by cooling summer surface temperatures. In contrast, afforestation in the northern extent of eastern North America with needleleaf evergreen trees provided no climate benefit by warming surface temperatures. The importance of latitude in afforestation projects has been highlighted by others using a range of approaches [6,16]. Furthermore, our simulation results agree with a previous study that used remote sensing data from the Moderate Resolution Imaging Spectro-radiometer (MODIS) satellite to estimate temperature differences between adjacent pixels with needleleaf evergreen and broadleaf deciduous trees [7].

Our results highlight that changes in albedo alone associated with afforestation can contribute to warmer temperatures in winter months, but that atmospheric feedbacks must be considered in summer months. Unexpectedly, we found that a gradient in temperature change, from warming in the north to cooling in the south, occurred during summer months despite similar changes in albedo across the region and no clear pattern in the latent heat flux change associated with afforestation (Figure 3). The primary driver of this temperature change gradient was a change in solar radiation that reached the land surface. In the northern extent, solar radiation increased with afforestation due to a reduction in cloud cover. In contrast, solar radiation did not change or decreased slightly in the southern extent (Figure 3). While it is difficult to determine which feedback processes allow changes in the surface energy balance from afforestation to propagate into changes in cloud cover, we hypothesize the lower air temperature in the northern extent in the baseline simulation (Grass) is closer to dew point temperature of the air column so additional heating from changes in surface heating associated with afforestation would increase the capacity of the air to hold water vapor and decrease cloudiness. Regardless, we show that there may be a gradient in how afforestation influences cloud cover within eastern North America that influences the climate benefit of afforestation during summer months. Future work should examine whether these feedbacks occur in simulations with less extreme changes in land cover than in our idealized simulations focused on examining sensitivities, as well as diagnose the atmospheric feedbacks leading to a change in cloud-cover.

Our finding that forest management (i.e., management of LAI and tree type) has a similar or greater influence on surface temperatures as land-cover change (afforestation) in the southern extent of eastern North America compares well to a prior study on flux tower measurements in ecosystems with contrasting forest management and land cover [10]. As defined by Luyssaert et al. [10], land-cover change is defined as the conversion between two vegetation types (e.g., grass to forest) and forest management is defined as human modifications of a vegetation type (e.g., fertilization and species selection). By comparing the surface temperature differences between flux towers in ecosystems with differing land cover and forest management, Luyssaert et al. [10] showed that forest management changes had a similar influence on temperature as land-cover change. Here, we simulated both simplified land-cover and forest management scenarios and found that forest management change resulted in a greater effect on temperatures than land-cover change in the southern extent of eastern North America. By explicitly including afforestation location in our analysis, our results build on those of Luyssaert et al. [10] and highlight the importance of latitude on the relative influence of land cover vs. forest management. We also note that Luyssaert et al. [10] included the management of additional land-cover types not included in our study. Additional CESM simulations using crops would allow for a better comparison. Finally, our use of a two-unit LAI change as a representation of management intensity is an oversimplification for which additional work is needed in order to refine how specific levels of management intensity alter the overall structure and biophysical properties of forests in model simulations.

Our focus here was on the biophysical mechanisms governing the effects of afforestation on surface temperature, as they are less well studied than the biogeochemical (i.e., carbon storage) mechanisms. Afforestation generally increases carbon storage through the accumulation of biomass, thus cooling climate by removing $CO_2$ from the atmosphere. Our findings suggest that biophysical mechanisms could at least partially counteract the cooling from carbon storage in the northern extent of eastern North America, but could reinforce cooling from carbon storage in the southern extent. Further modeling studies that combine biogeochemical and biophysical processes, while isolating the influence of tree type and level of LAI used in afforestation projects, are required to fully quantify the influence of afforestation in eastern North American on regional and local climate.

## 5. Conclusions

The CESM provided a valuable approach for evaluating how different management decisions mediate the biophysical effects of afforestation from a grass to forest ecosystem on surface air temperature. Given that our results are contingent on a single, though widely used, Earth system model and the design of the modeling study oversimplified potential land-cover and land management change in eastern North America, our results should not be interpreted as a predicted change in temperature for a particular afforestation project. Additional work that evaluates the CESM predictions using paired flux towers and that simulates more realistic afforestation scenarios should be performed to gain confidence in predictions. However, as an examination of the model sensitivity, our study highlights how the representation of temperate forest management in Earth System Models could potentially be as important as the representation of land-cover change for determining how the physical modification of the land surface may be altering climate.

**Acknowledgments:** Funding support came from USDA-NIFA Project 2015-67003-23485 and the Pine Integrated Network: Education, Mitigation, and Adaptation project (PINEMAP), a Coordinated Agricultural Project funded by the USDA National Institute of Food and Agriculture, Award #2011-68002-30185. Computational support was provided by Virginia Tech Advanced Research Computing. Additional support came from USDA McIntire-Stennis funding to Virginia Tech.

**Author Contributions:** B.J.A. and R.Q.T. conceived the ideas and designed methodology; B.J.A. performed the simulations; B.J.A. and R.Q.T. analyzed the simulations; B.J.A. and R.Q.T. wrote the manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Bonan, G.B. Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests. *Science* **2008**, *320*, 1444–1449. [CrossRef] [PubMed]
2. Anderson, G.R.; Canadell, J.G.; Randerson, J.T.; Jackson, R.B.; Hungate, B.A.; Baldocchi, D.D.; Ban-Weiss, G.A.; Bonan, G.B.; Caldeira, K.; Cao, L.; et al. Biophysical Considerations in Forestry for Climate Protection. *Front. Ecol. Environ.* **2011**, *9*, 174–182. [CrossRef]

3. Field, B.C.; Lobell, D.B.; Peters, H.A.; Chiariello, N.R. Feedbacks of Terrestrial Ecosystems to Climate Change. *Annu. Rev. Environ. Resour.* **2007**, *32*, 1–29. [CrossRef]
4. Betts, R.A. Offset of the Potential Carbon Sink from Boreal Forestation by Decreases in Surface Albedo. *Nature* **2000**, *408*, 187–190. [CrossRef] [PubMed]
5. Bala, G.; Caldeira, K.; Wickett, M.; Phillips, T.J.; Lobell, D.B.; Delire, C.; Mirin, A. Combined Climate and Carbon-Cycle Effects of Large-Scale Deforestation. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 6550–6555. [CrossRef] [PubMed]
6. Li, Y.; Zhao, M.; Motesharrei, S.; Mu, Q.; Kalnay, E.; Li, S. Local Cooling and Warming Effects of Forests Based on Satellite Observations. *Nat. Commun.* **2005**, *6*, 6603. [CrossRef] [PubMed]
7. Zhao, K.; Jackson, R.B. Biophysical Forcings of Land-Use Changes from Potential Forestry Activities in North America. *Ecol. Monogr.* **2016**, *84*, 329–353. [CrossRef]
8. Jackson, B.R.; Randerson, J.T.; Canadell, J.G.; Anderson, R.G.; Avissar, R.; Baldocchi, D.D.; Bonan, G.B.; Caldeira, T.R.; Diffenbaugh, N.S.; Field, C.B.; et al. Protecting Climate with Forests. *Environ. Res. Lett.* **2008**, *3*, 269. [CrossRef]
9. Breuer, L.; Eckhardt, K.; Frede, H.G. Plant Parameter Values for Models in Temperate Climates. *Ecol. Model.* **2003**, *169*, 237–293. [CrossRef]
10. Luyssaert, S.; Jammet, M.; Stoy, P.C.; Estel, S. Land Management and Land-Cover Change Have Impacts of Similar Magnitude on Surface Temperature. *Nat. Clim.* **2104**, *4*, 389–393. [CrossRef]
11. Hansen, C.M.; Potapov, P.V.; Moore, R.; Hancher, M.; Turubanova, S.A.; Tyukavina, A.; Thau, D.; Stehman, S.V.; Goetz, S.J.; Loveland, T.R.; et al. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **2013**, *342*, 850–853. [CrossRef] [PubMed]
12. Vose, M.J.; Allen, H.L. Leaf Area, Stemwood Growth, and Nutrient Relationships in Loblolly Pine. *For. Sci.* **1998**, *34*, 547–563.
13. Albaugh, J.T.; Allen, H.L.; Dougherty, P.M.; Johnsen, K.H. Long Term Growth Responses of Loblolly Pine to Optimal Nutrient and Water Resource Availability. *For. Ecol. Manag.* **2004**, *192*, 3–19. [CrossRef]
14. Bonan, G. *Ecological Climatology*, 3rd ed.; Cambridge University Press: New York, NY, USA, 2016.
15. Wickham, D.J.; Wade, T.G.; Riitters, K.H. Empirical Analysis of the Influence of Forest Extent on Annual and Seasonal Surface Temperatures for the Continental United States. *Glob. Ecol. Biol.* **2012**, *22*, 620–629. [CrossRef]
16. Peng, S.S.; Piao, S.L.; Zeng, Z.; Ciais, P.; Zhou, L.; Li, L.Z.X.; Myneni, R.B.; Yin, Y.; Zeng, H. Afforestation in China Cools Local Land Surface Temperature. *Proc. Natl. Acad. Sci. USA* **2014**, *11*, 2915–2919. [CrossRef] [PubMed]
17. Chen, G.; Notaro, M.; Liu, Z.; Liu, Y. Simulated Local and Remote Biophysical Effects of Afforestation over the Southeast United States in Boreal Summer. *J. Clim.* **2012**, *25*, 4511–4522. [CrossRef]
18. Murphy, N.L.; Riley, W.J.; Collins, W.D. Local and Remote Climate Impacts from Expansion of Woody Biomass for Bioenergy Feedstock in the Southeastern United States. *J. Clim.* **2012**, *25*, 7643–7659. [CrossRef]
19. Hurrell, W.J.; Holland, M.M.; Gent, P.R.; Ghan, S.; Kay, J.E.; Kushner, P.J.; Lamarque, J.F.; Large, W.G.; Lawrence, D.; Lindsay, K.; et al. The Community Earth System Model: A Framework for Collaborative Research. *Bull. Am. Meteorol. Soc.* **2013**, *94*, 1339–1360. [CrossRef]
20. Oleson, K.; Lawrence, D.M.; Bonan, G.B.; Drewniak, B.; Huang, M.; Koven, C.D.; Levis, S.; Li, F.; Riley, W.J.; Subin, Z.M.; et al. *Technical Description of Version 4.5 of the Community Land Model (CLM)*; NCAR Technical Note NCAR: Boulder, CO, USA, 2013. [CrossRef]
21. Lee, X.; Goulden, M.L.; Hollinger, D.Y.; Barr, A.; Black, T.A.; Bohrer, G.; Bracho, R.; Drake, B.; Goldstein, A.; Gu, L.H.; et al. Observed Increase in Local Cooling Effect of Deforestation at Higher Latitudes. *Nature* **2011**, *479*, 384–387. [CrossRef] [PubMed]