Reductions in land surface temperature induced by forest management in Fennoscandia revealed by machine learning models

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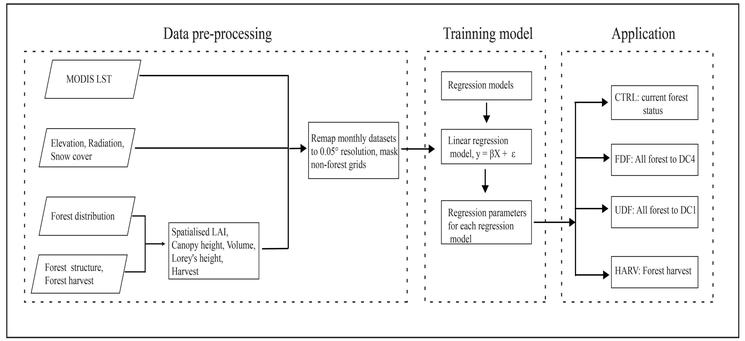
1. Introduction

Forests affect the local climate through a variety of biophysical mechanisms. Observational and modelling studies have investigated the effects of forested vs. non-forested areas, but the influence of forest management on surface temperature has received far less attention owing to the inherent challenges to adapt climate models to cope with forest dynamics. Further, climate models are complex and highly parameterized, and the time and resource intensity of their use limit applications. The availability of simple yet reliable statistical models based on high resolution maps of forest attributes at various development stages can link individual forest management practices to local temperature changes, and ultimately support the design of improved strategies. In this study, we investigate how forest management influences local surface temperature (LST) in Fennoscandia through a set of machine learning algorithms.

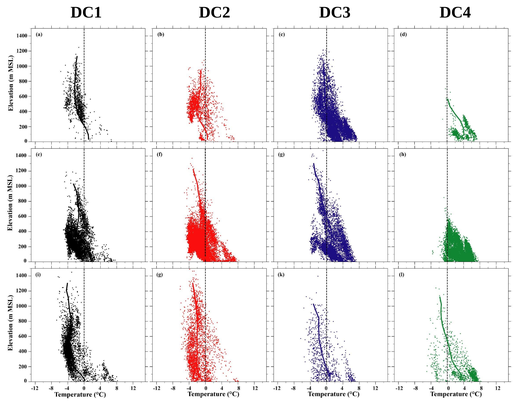
Highlight

- A machine learning based statistical system is used to predict effects of forest management on LST
- The system can accurately reproduce the observed LST in Fennoscandian forests
- More developed forests are typically associated with higher LST than young or undeveloped forest
- Historical forest management had a light mean annual cooling, but increased LST in the summer
- The approach is flexible and can be applied at various scales and different management scenarios

2. Flowchart summarizing the key steps of our analysis

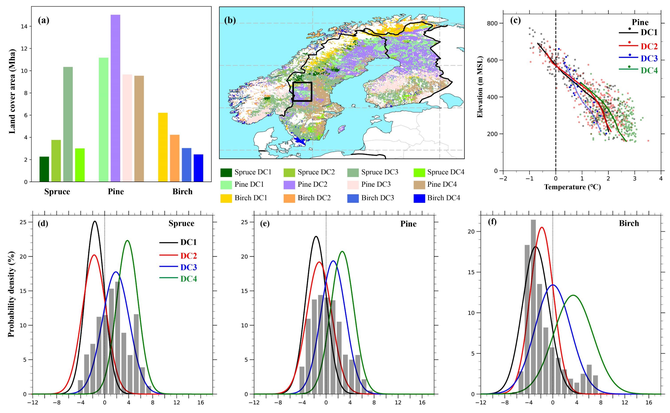


3. LST in Fennoscandia across the elevation gradient for forests and DC



- Annual mean clear-sky LST is generally increasing with the forest development class
- Across an elevation gradient of an area experiencing similar climatic conditions (see black box in section 5, figure b and c), the average annual mean LST of a pine-dominated forest tends to be warmer for DC4 than DC2 and DC1, especially at low elevation
- For all tree species, and for nearly all elevation ranges, higher LST values are found for higher development classes

4. Forest distribution in Fennoscandia and associated annual mean clear-sky LST



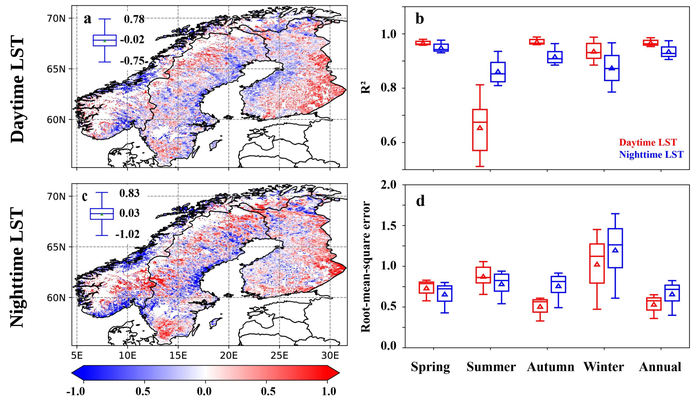
(a) Land cover area of four DC for spruce, pine, and birch

(b) forest distribution

(c) Annual mean LST over an elevation profile

(d) -(f) PDF of annual average LST for four DC forest

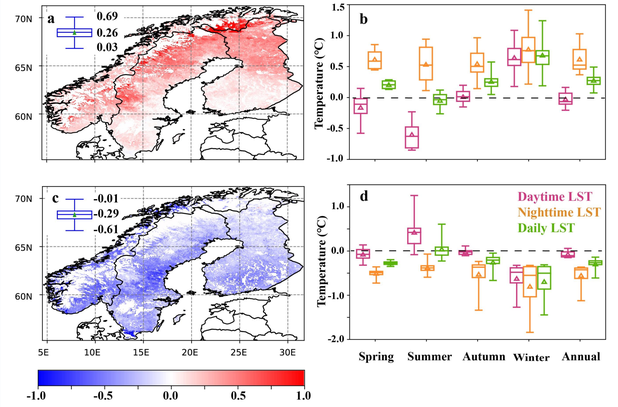
5. Performance of the multiple regressor system in reproducing LST



Model	Regression family	Reference	Code repository
bagEarth	Bagging	Kuhn (2019)	http://topepo.github.io/caret/train-models-by-tag.html#bagging
bMachine	Bayesian models	Kapelner and Bleich (2016)	https://cran.r-project.org/web/packages/bartMachine/index.html
cubist	Regression rules	Quinlan (1992)	https://pypi.org/project/cubist/
earth	Additive models	Friedman (1991)	https://contrib.scikit-learn.org/py-earth/
extraTrees	Random forests	Geurts et al. (2006)	https://scikit-learn.org/stable/modules/generated/sklearn.ensemble.ExtraTreesRegressor.html
gbm	Boosting	Greenwell et al. (2022)	https://cran.r-project.org/web/packages/gbm/index.html
svr	Support vector regression	Chang and Lin (2011)	https://scikit-learn.org/stable/modules/generated/sklearn.svm.SVR.html

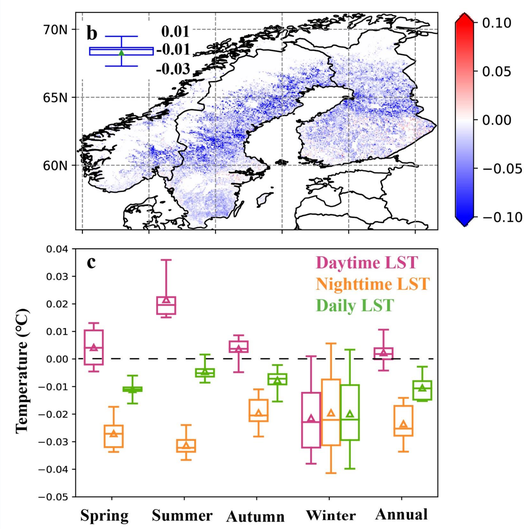
- We employ seven regression models to build to build the multiple regressor system
- Compared to observations, both daytime and night-time LSTs show nearly symmetrical bias scattered all over the domain without any relevant cluster
- For the seasonal and annual mean daytime and night-time LST, the temperature differences between simulated and observed LST shows a gaussian distribution with a near zero mean

6. LST induced from idealized forest management scenarios



- Relative to the present state of Fennoscandian forests, fully develop forests (FDF) are found to induce an annual mean warming of 0.26 ℃
- An average cooling effect in the summer daytime from -0.85 to -0.23 ℃ (depending on the model) in FDF
- A scenario with undeveloped forests (UDF) induces an annual average cooling of -0.29 ℃

7. Effects of historical forest management on LST



- From 2015 to 2018, about 252 million m3 of roundwood was harvested in Finland, 49 million m3 in Norway and 296 million m3 in Sweden
- A largely homogeneous multi-model annual mean cooling of -0.01 ℃ associated with the historical harvest, with confidence intervals (5th and 95th percentiles) ranging from -0.03 ℃ to +0.01 ℃
- The seasonality shows that the day- and night-time LST response have opposite sign but similar magnitude in summer, while in winter they are both negative (e.g., cooling), except for one model (earth)
- In particular, a cooling effect at night is observed throughout the year, while daytime temperature increases in all seasons but winter

8. Summary

This study offers a simplified statistical approach to assess the effects of forest management on land surface temperature in Fennoscandia. We found a consistent pattern in the domain of higher mean surface temperature in presence of more developed forests relative to poorly structured forests, indicating that changes induced by forest management contribute to shape the local climate. The multi-model mean estimates from the regression system made of seven machine-learning models can reproduce the temperature values observed in the forest at reasonable accuracy, and thanks to their integration with high resolution maps of forest attributes can assess the influence of forest management on local temperature.

More details and additional references can be found in:

Huang, B., Li, Y., Liu, Y., Hu, X., Zhao, W., & Cherubini, F. (2023). A simplified multi-model statistical approach for predicting the effects of forest management on land surface temperature in Fennoscandia. Agricultural and Forest Meteorology, 332, 109362. https://doi.org/10.1016/j.agrformet.2023.109362