The Climatic Significance of Biogenic Aerosols in the Boreal Region Now and in the Future

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Abstract

The magnitude of aerosol radiative effects remains the single largest uncertainty in current estimates of anthropogenic radiative forcing. One of the key quantities needed for accurate estimates of anthropogenic radiative forcing is an accurate estimate of the radiative effects from natural aerosol. The dominant source of natural aerosols over Earth's forested regions is biogenic volatile organic compounds (BVOC) which, following oxidation in the atmosphere, can participate in new particle formation or condense onto aerosols to form secondary organic aerosol (SOA). Consequently, BVOC emissions could introduce a regionally relevant cooling feedback in a warming climate. The main objective of this study is to provide a quantitative estimate of the regional aerosol direct radiative effect caused by the temperature-dependent biogenic emissions over the boreal forests in present day conditions and in a warmer future. The study is done using a combination of climate modeling and satellite data. The aerosol-chemistry climate model used is ECHAM-HAMMOZ, which describes the relevant atmospheric aerosol processes. The BVOC emissions are computed online using the MEGAN model, which enables the simulation of the effects of temperature changes on atmospheric aerosol load. Key remote sensing data used are the AATSR based aerosol optical depth (AOD) and land surface temperature (LST) products available from the Aerosol-CCI and GlobTemperature projects, together with ancillary data, such as column concentrations of CO and water vapour from AIRS, and NO2 column densities from OMI. Our analysis shows that there could be a small temperature dependence in AOD over the boreal forests but it cannot be reliably detected from the simulations or observations. The only subregion with a clear temperature dependence in AOD was found over western Russia. Anthropogenic emissions affect this subregion more than the other regions analyzed thus, it is likely that in addition to BVOC emissions hygroscopic sulfate aerosols affect the temperature dependence of AOD. In a warmer future the clear-sky radiative forcing caused by biogenic aerosols will increase, following the increase of BVOC emissions, but if anthropogenic emissions will decrease at the same time the total clear-sky forcing will also decrease.

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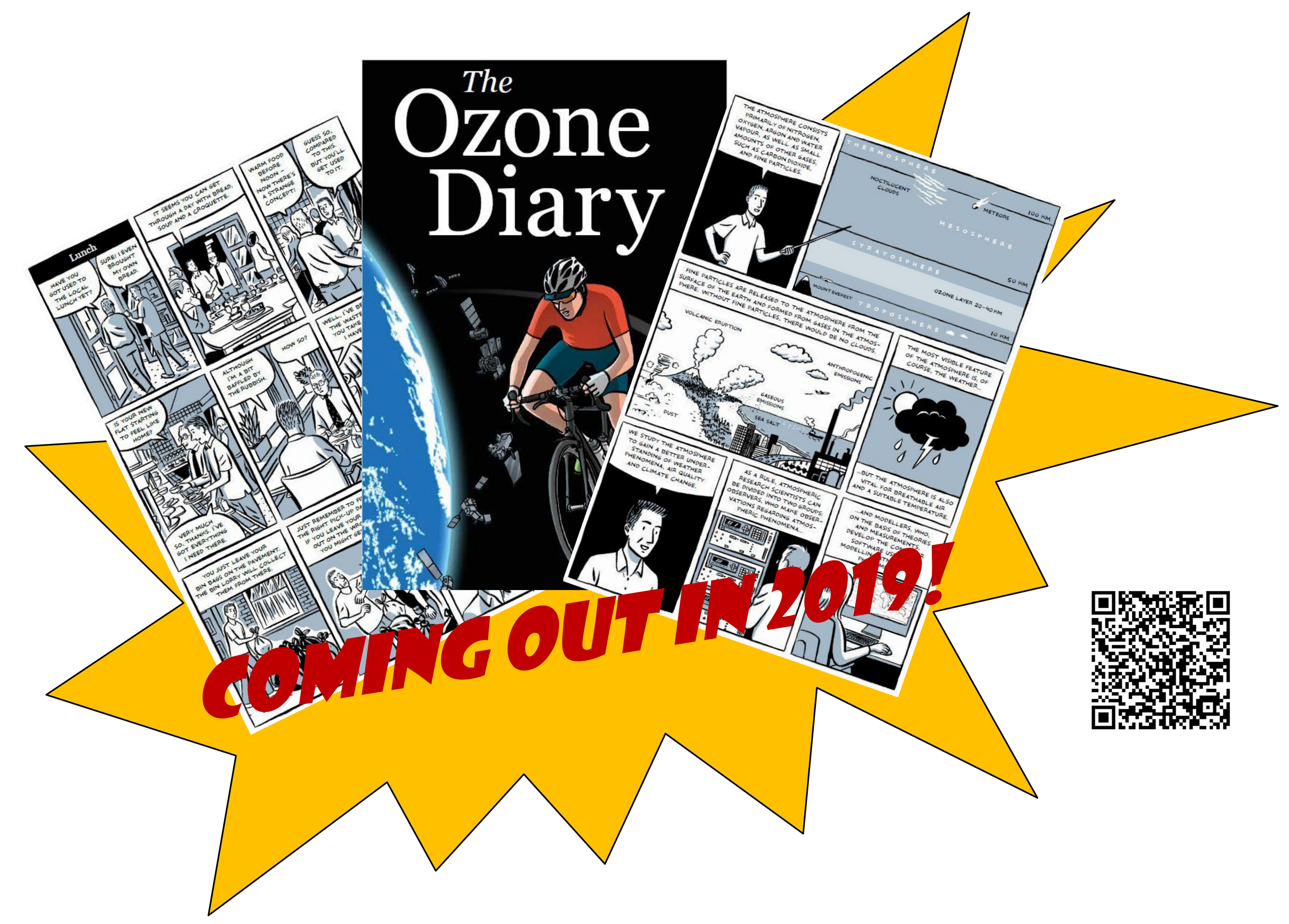


1. INTRODUCTION

We have quantified the radiative effects of temperature dependent aerosol optical depth (AOD) over the southeastern USA (Mielonen et al. 2018).

- the temperature-dependent AOD component was linked to biogenic volatile organic compounds (BVOCs)

Boreal forests also emit significant amounts of BVOCs during summers (JJA) so we used climate modeling and satellite remote sensing to see if we could quantify the aerosol radiative effects of these BVOC emissions.

2. METHODS

Climate model: **ECHAM6.1-HAM2.2-SALSA** (Kokkola et al., 2018)

- T63L31-resolution (1.9° × 1.9°, 31 vertical levels)
- 11-year simulations (CTRL + noBioSOA) for present day (**PRES**: 2006-2016), future (**FUT**: 2045-2055), and future with current emissions (**FUT$_{emi12}$**)
- free runs with SST and SIC (CMIP5) averaged over 11 years
- ACCMIP emissions for 2012 and 2050 (RCP8.5)

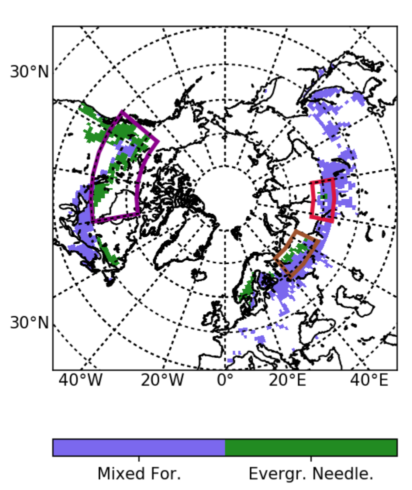
Satellite data (2005-2011, Level 3)

- **AATSR**: Land surface temperature (LST), Aerosol optical depth (AOD)
- **AIRS**: Carbon Monoxide (CO)
- **OMI:** Nitrogen Dioxide (NO_2)
- **MODIS**: Thermal Anomalies (FRP), Land cover types (IGBP)
- Products mainly collocated to a daily, 1° × 1° grid
- To avoid smoke contribution we only analyzed pixels with
  - air masses coming from the north (based on ERA-Interim data)
  - no thermal anomalies in the surrounding pixels or north of the pixel
  - no anomalously high CO/AOD concentrations

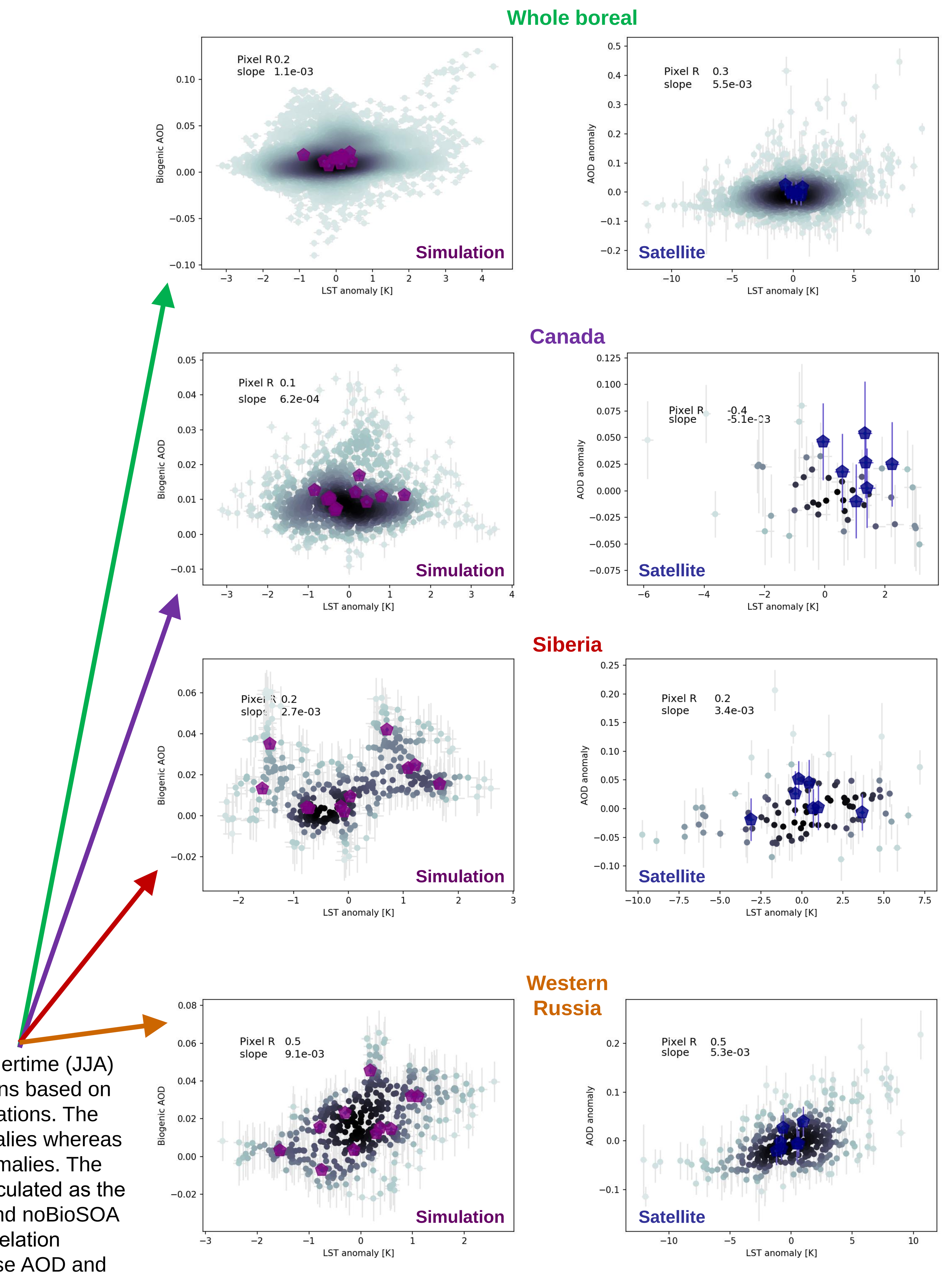
Comparisons were done using pixel-wise anomalies together with regional anomalies

3. RESULTS

The boreal forests (mixed forests and evergreen needleleaf forests) were analyzed as a whole and subregional analyses were done for Canada, Siberia and Western Russia.



The relationship between summertime (JJA) AOD and LST over boreal regions based on simulations and satellite observations. The dots represent pixel-wise anomalies whereas the pentagons are regional anomalies. The simulated "biogenic AOD" is calculated as the difference between the CTRL and noBioSOA simulations. "Pixel R" is the correlation coefficient between the pixel-wise AOD and LST values and the "slope" is the slope of the corresponding linear fit.



The table below lists the simulated climatic effects of biogenic aerosols over the whole boreal forest region. *AOD* is the total AOD, *bioAOD* is the biogenic part of AOD, *bioFORcl* is the clear-sky forcing of biogenic aerosols, *bioFORall* is the the all-sky forcing of biogenic aerosols and accordingly, *FORcl* and *FORall* are the clear-sky and all-sky forcings of the total aerosol load. *PRES* is the present day simulation whereas Δ*FUT* and Δ*FUT$_{emi12}$* are the changes between the present day simulation and the future simulations. Positive changes indicate larger values in the future. The average summertime temperature in the studied region is ~ 2 K warmer in the future simulations.

SUMMER (JJA)	bioAOD	AOD	bioFORcl [W/m²]	FORcl [W/m²]	bioFORall [W/m²]	FORall [W/m²]	Cloud cover [%]
PRES (2012)	0.015	0.083	-0.63		-0.27		72
ΔT ~ 2 K	*Change from present day*						
ΔFUT (2050)	*0.004*	*-0.023*	*-0.26*	*0.62*	*-0.12*	*-0.27*	*-4*
ΔFUT$_{emi12}$	*0.006*	*0.008*	*-0.21*	*-0.27*	*-0.12*	*-0.35*	*-4*

4. CONCLUSIONS AND TAKE-AWAY MESSAGE

No clear relationship between AOD and LST was found over the whole boreal region

- One region exhibited a clearer dependence probably due to higher anthropogenic emissions
- Simulations were in good agreement with satellite observations

In the future, clear-sky aerosol forcing is expected to decrease if anthropogenic emissions decrease even though biogenic emissions increase

- All-sky forcing will increase in a warmer future and biogenic emissions contribute approximately one third to it

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