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Future projection on Siberian wildfire and its aerosol emissions by the improved fire module of Spatially Explicit Individual Based Dynamic Global Vegetation Model

(空間明示的個体ベース動的全球植生モデルの改良型火災モジュールによるシベリア林野火災とそれによるエアロゾル排出量の将来予測)

Fire is one of the most significant disturbances, globally affecting biogeochemical cycles, atmospheric chemistry, carbon cycle, and ecosystem structure and function. The effects of wildfires are becoming increasingly severe due to climate change, it is estimated that the global mean CO₂ emission intensity has increased by $0.9 \pm 0.9\%$ year⁻¹ from 2000 to 2019. Siberia has the largest forest biome and one-third of global forest cover and one of among the regions impacted by intense wildfires annually that affects the atmosphere–land interactions of the global climate. Modeling of fire regimes using dynamic global vegetation models (DGVMs) is a key approach to analyzing these factors. However, including interactive fire disturbances in vegetation models is critical for accurately simulating vegetation dynamics. Therefore, in this study, the widely used process based fire module (SPITFIRE) was integrated into the spatially explicit individual-based dynamic global vegetation model (SEIB-DGVM) to predict fire, vegetation, and burned biomass emission variables in Siberia in the future.

The SEIB-DGVM fire module was improved by replacing the Glob-FIRM with the SPITFIRE model. First, the model: SEIB-DGVM was modified to add two new input variables for fire ignition: population and lightning data. Second, the complete SPITFIRE equation was integrated on the model. The model was run in three phases under fire-on and fire-off mode and each phase repeated 5 time: 1) a 1000-year spin-up phase to bring the soil and vegetation carbon pools into equilibrium with the climate using daily baseline CRU TS3.22 climate data, 2) a 156-year historical phase also using daily baseline CRU TS3.22 climate data, and 3) a 95-year future phase using daily MIROC-AR5 base V2 RCPs 8.5, 6.0, 4.5, and 2.6 climate data. Finally, to ensure that the simulation results and the projections data are in line with the observational data, the model outputs validated

by using GFED4, GFED4s, ESA Biomass CCI and GEDI benchmark datasets.

The model is able to reproduce historical data that well compared to the benchmark datasets. Overall, on spatial comparison, the model is able to produce data with the same distribution pattern with a value of 61.8% compared to the benchmark datasets. Numerically and on a long-term average, the model is able to produce values with very high accuracy of around 99% compared with the benchmark datasets. The model estimated that until 2100, Siberia will continue to experience an increase in the frequency of forest fires. Under the RCP8.5 climate scenario, the CO₂, CO, PM_{2.5}, total particulate matter (TPM), and total particulate carbon (TPC) emissions in Siberia will continue to increase annually until 2100 by 0.0264 ± 0.01 % year⁻¹ or individually by 214.4 ± 79.4 , 17.16 ± 6.35 , 2.8 ± 1.03 , 2.1 ± 0.78 , and 1.47 ± 0.54 Gg species year⁻¹, respectively. Under the same scenario and period, 185 trees ha⁻¹ year⁻¹ are estimated to be killed by wildfires, resulting in a 319.3 g C m⁻² year⁻¹ loss of net primary production (NPP).

The model modifications have led to a more realistic depiction of fire frequency, intensity, and extent, aligning the model outputs more closely with benchmark datasets. The major variables reached an agreement of 61.8% or greater with the observations. Additionally, the improved model accurately simulated forest structure, increasing the agreement between the simulated and observed dataset patterns and further emphasizing the reliability of the model and its emission projections.