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Supplement of

Trends and spatial shifts in lightning fires and smoke concentrations in response to 21st century climate over the national forests and parks of the western United States

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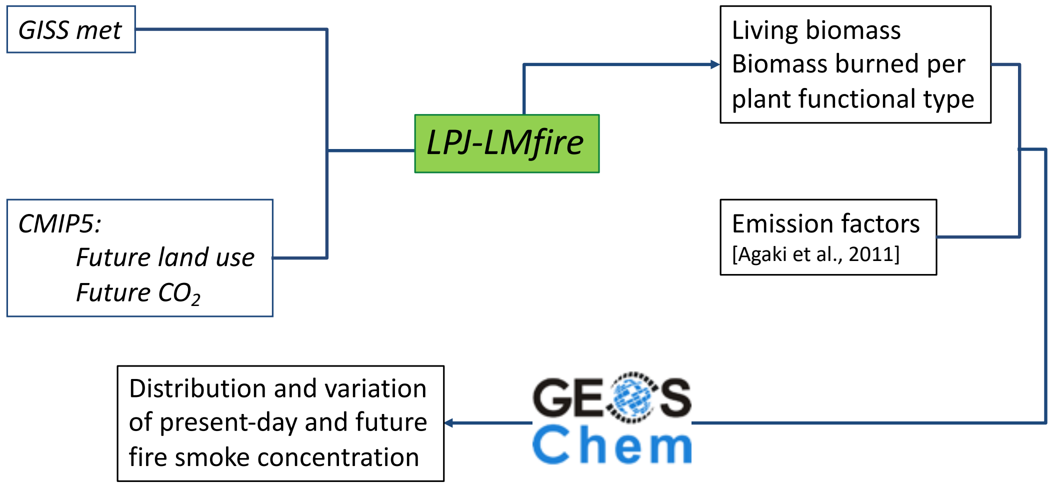

Fig. S1. Flowchart of modeling setup.

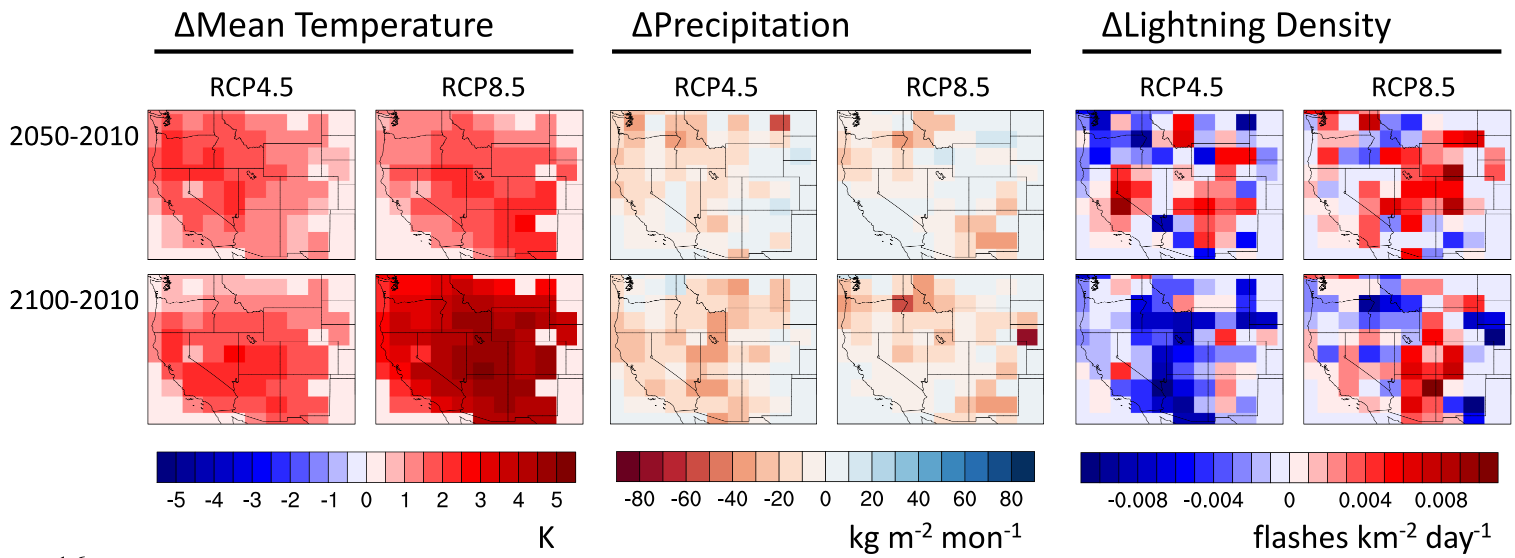

Fig. S2. Changes in monthly mean temperature, precipitation and lightning density averaged over the fire season in the western U.S. for the RCP4.5 and RCP8.5 scenarios. The top row shows changes between the present day and 2050, and the bottom row shows changes between the present day and 2100. Temperature and precipitation are from GISS-E2-R for the RCP4.5 and RCP8.5 scenarios, with five years representing each time period. Lightning density is calculated using the GISS convective mass flux following the empirical parameterization of *Magi* [2015]. The fire season is July, August, and September.

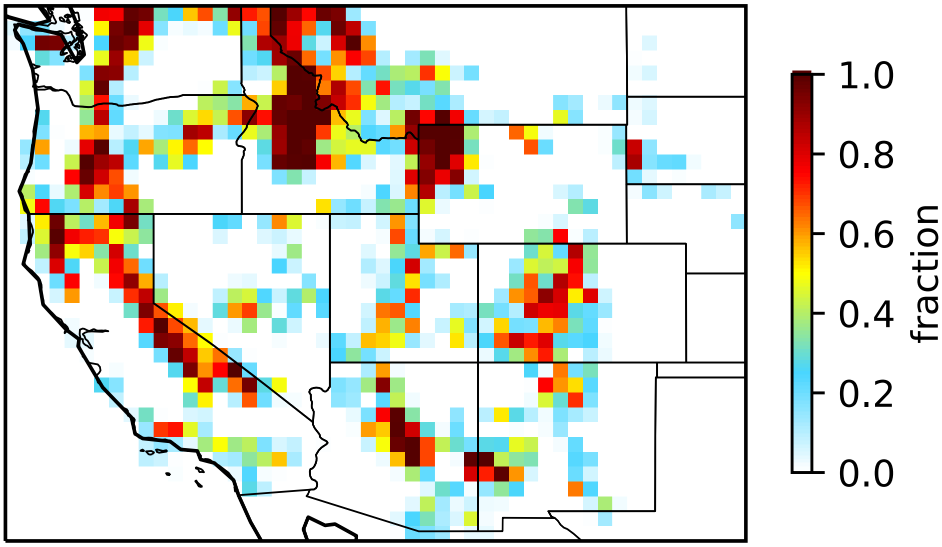

Fig. S3. Map of the National Forest and Park fraction.

Evaluation of LPJ-LMfire fire emissions

We first evaluate the lightning-caused wildfire emissions from LPJ-LMfire over the National Forests in the western U.S. by comparing with the Global Fire Emissions Database (GFED4s) emissions over the same regions (Fig. S4). Lightning is the dominant fire source over the western U.S. forests, allowing a reasonable comparison between the two emission inventories over the forest areas in the West. The total fire-season dry matter burned (DM) over National Forests and Parks from LPJ-LMfire is 22.11 Tg for July-August-September (JAS), comparable to that from GFED4s (19.89 Tg), providing confidence in the LPJ-LMfire representation of fires without active suppression. GFED4s shows greater DM over northern Washington, Idaho, and northern California than LPJ-LMfire but overall the spatial mismatches are not large.

We then validate the carbonaceous fine particulate matter ($PM_{2.5}$; BC+OC) generated by GEOS-Chem in a simulation with the combined emissions (LPJ-LMfire over the National Forests and Parks and GFED4s elsewhere) during JAS. Simulated BC and OC also include contributions from non-fire sources, such as fossil fuel combustion from transportation, industry, and power plants. We compare the GEOS-Chem results against ground-based measurements from the Interagency Monitoring of Protected Visual Environments (IMPROVE) network in the western U.S. We find that GEOS-Chem generally reproduces the IMPROVE observations, with elevated concentrations (~3.0-5.0 $\mu g\ m^{-3}$) over the northern states and in California (Fig. S5). The finer-resolution simulation provides more detailed distributions of fire activity in the western U.S., which are of greater utility to environmental managers. In JAS, large amounts of smoke PM are transported from Canada, as implied by some IMPROVE observations in Idaho and Montana. GFED4s includes the smoke from these Canadian fires, as reflected by elevated smoke PM in the northeast corner of the domain in the GEOS-Chem results. Results in RCP8.5 for the present-day are similar to those under RCP4.5 (not shown). We also compare 5-year fire-season averages of smoke PM in each grid cell in the western U.S. from GEOS-Chem against those from IMPROVE observations (Fig. S6). The GEOS-Chem simulation with combined emissions generally reproduces smoke PM within an uncertainty of 50%.

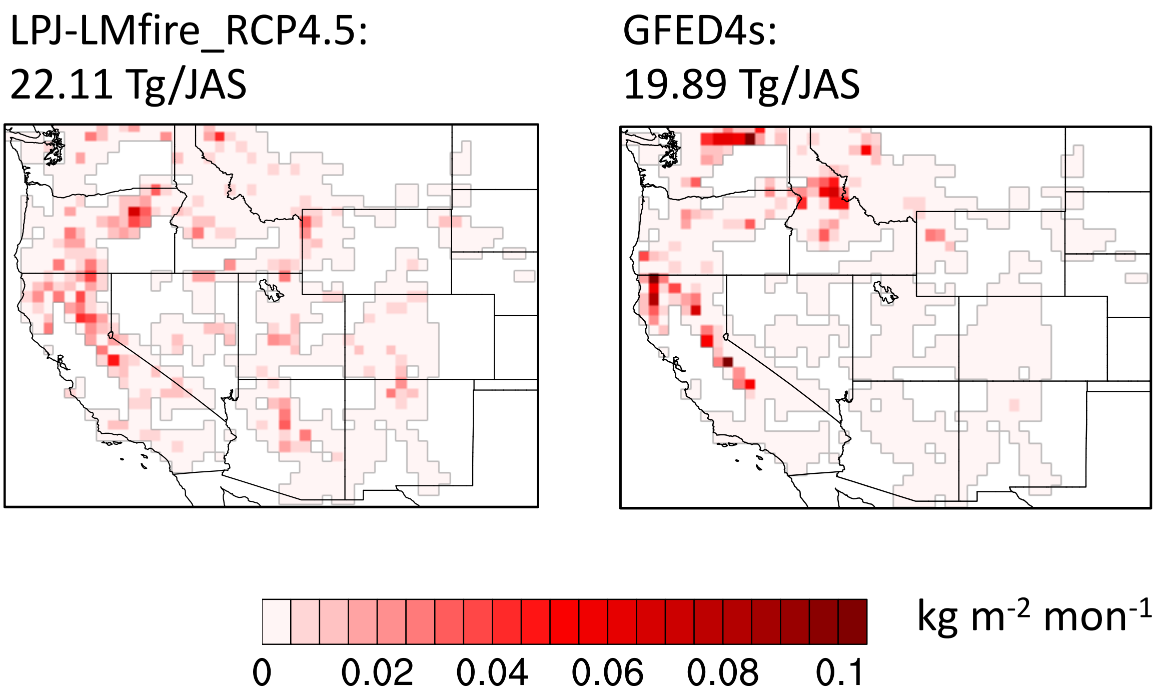

Fig. S4. Present-day (2011-2015) fire-season averaged lightning-caused dry matter burned (DM) over the national forests and parks in the western U.S. for LPJ RCP4.5 and GFED4s. Value are the total fire-season DM over the national forests and parks in the two inventories. The fire season is July, August, and September. White spaces indicate areas outside the national forests and parks.

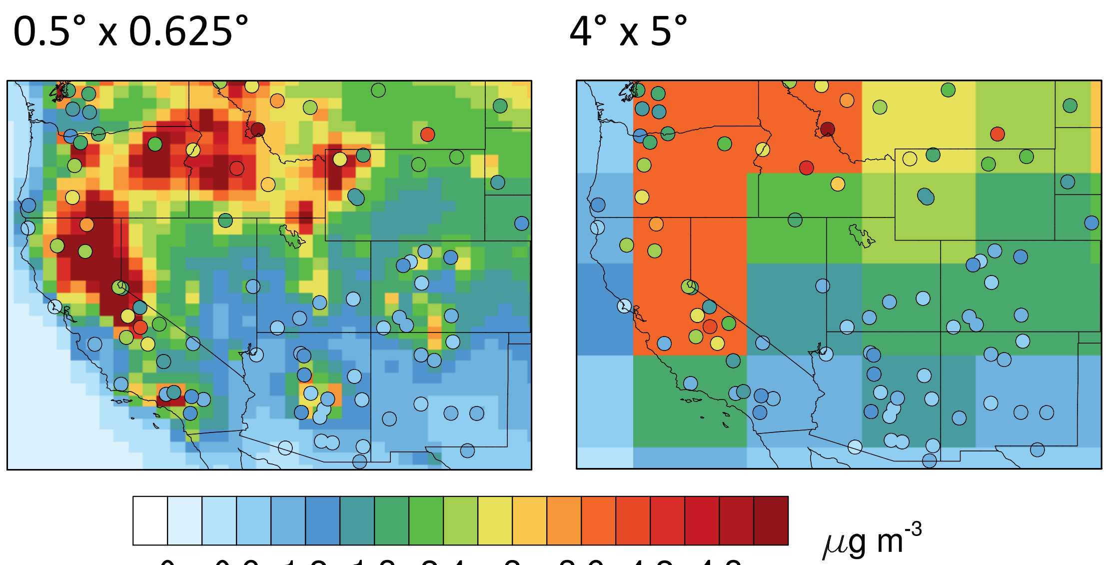

Fig. S5. Fire-season averaged smoke PM. Circles represent ground-based observations from the IMPROVE network. The colored background is from GEOS-Chem simulations at 0.5° x 0.625° and 4° x 5° spatial resolutions for the present-day (2011-2015) using the combined fire emissions from LPJ-LMfire over the national forests and parks and GFED4s over other regions. The fire season is July, August, and September.

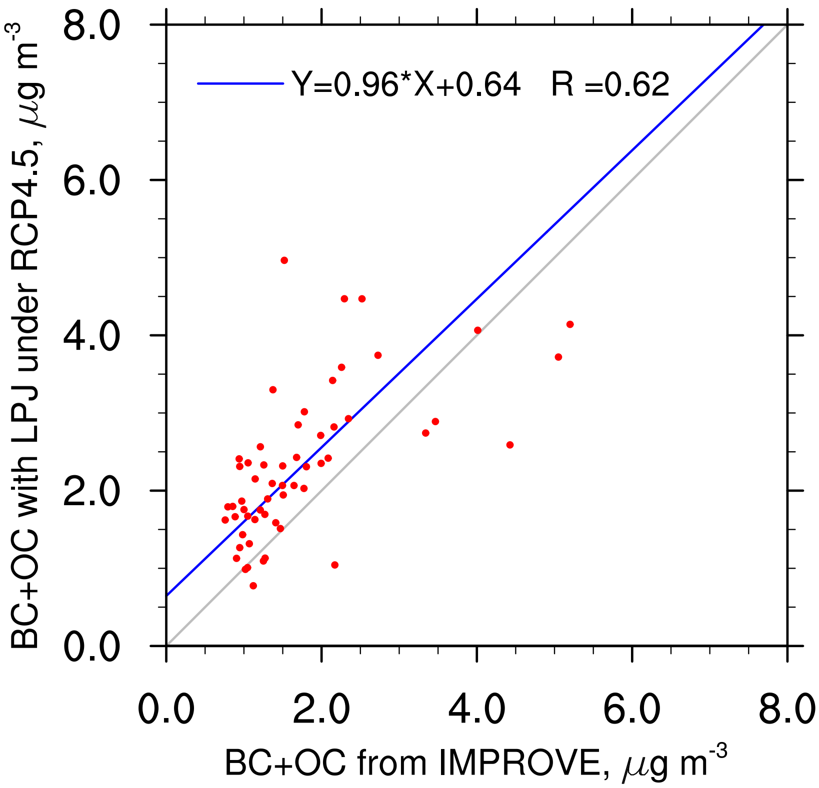

Fig. S6. BC+OC concentrations simulated with the present-day combined fire emissions from LPJ RCP4.5 (over National Forests) and GFED4s (over other regions) compared to those from IMPROVE observations. Each dot represents the 5-year fire-season average of concentrations in each grid square (with the resolution of 4° x 5°) across the western U.S. The blue line is the fitted line using reduced major axis (RMA) regression between the GEOS-Chem simulations and those from IMPROVE. The grey line denotes the 1:1 line.

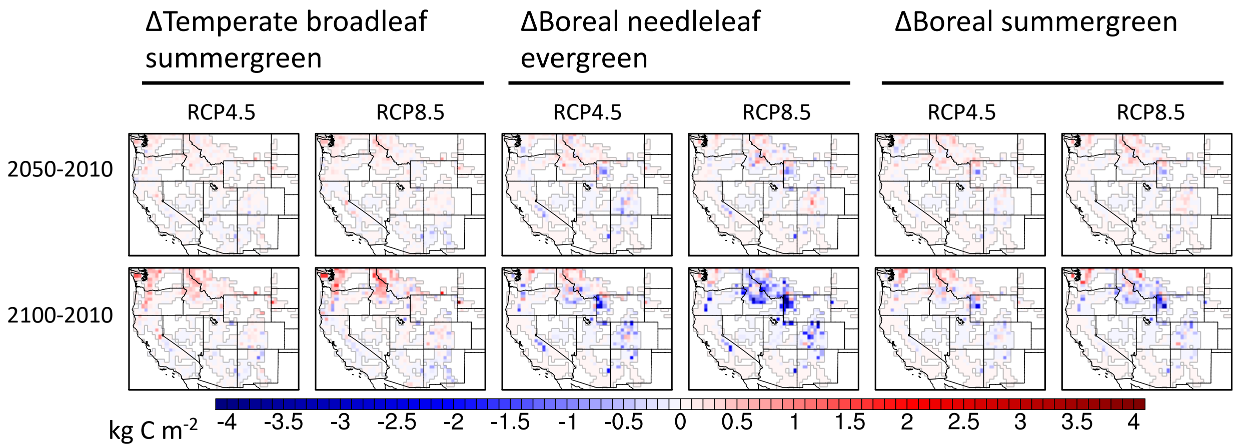

Fig. S7. Simulated changes in living biomass for the three most dominant plant functional types over the national forests and parks in the western U.S. for the RCP4.5 and RCP8.5 scenarios. The top row shows changes between the present day and 2050, and the bottom row shows changes between the present day and 2100. Results are from LPJ-LMfire, with five years representing each time period. The fire season is July, August, and September. White spaces indicate areas outside the national forests and parks.

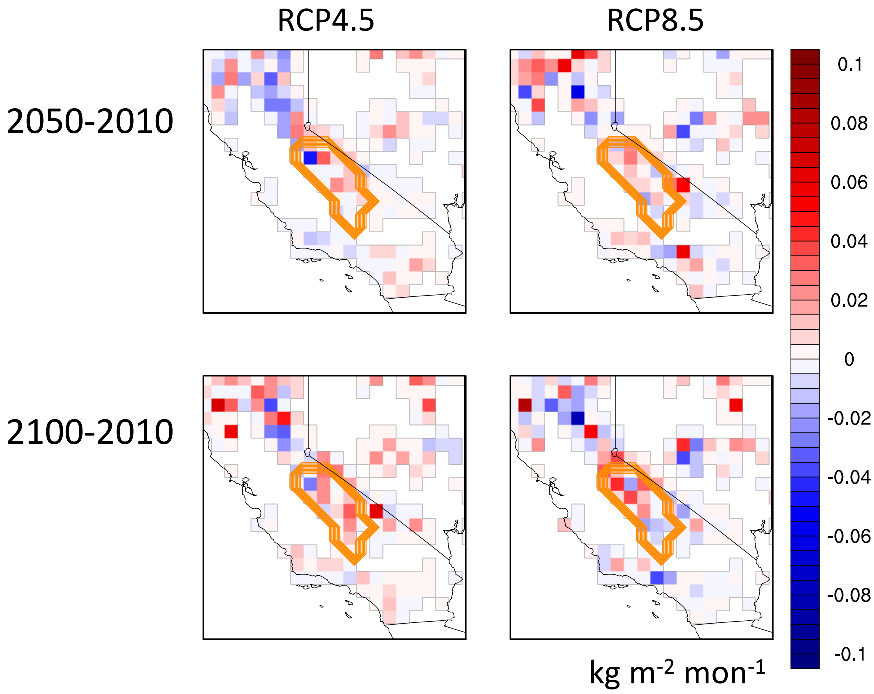

Fig. S8. Simulated changes in monthly mean lightning-caused DM averaged over the fire season over the national forests and parks in California for the RCP4.5 and RCP8.5 scenarios. The top row shows changes in DM between the present day and 2050, and the bottom row shows changes between the present day and 2100. Results are from LPJ-LMfire for the RCP4.5 and RCP8.5 scenarios, with five years representing each time period. The fire season is July, August, and September. Bold orange lines mark the boundaries of the Sierra Nevada (SN). White spaces indicate areas outside the national forests and parks.

Table S1. Reclassification of LPJ-LMfire PFTs.

LPJ-LMfire (9 pfts)	**GEOS-Chem (6 pfts)**
Tropical broadleaf evergreen	Tropical forest
Tropical broadleaf raingreen	Tropical forest
Temperate needleleaf evergreen	Temperate forest
Temperate broadleaf evergreen	Temperate forest
Temperate broadleaf summergreen	Temperate forest
Boreal needleleaf evergreen	Boreal forest
Boreal summergreen	Boreal forest
C_3 grass	Crop, pasture
C_4 grass	*50% ->* savanna, grassland, shrubland; 50% -> crop, pasture