Supplementary material

Response of dust emissions in southwestern North America to 21st century trends in climate, CO_2 fertilization, and land use: Implications for air quality

Yang Li[1], Loretta J. Mickley[1], Jed O. Kaplan[2]

[1]John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA, USA

[2]Department of Earth Sciences, The University of Hong Kong, Hong Kong, China

Correspondence to: Yang Li (yangli@seas.harvard.edu)

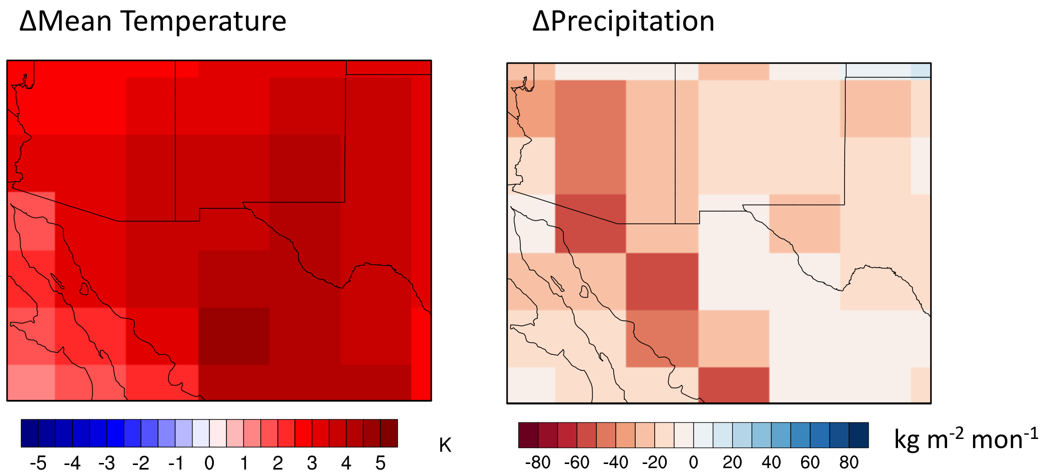

Figure S1. GISS-E2-R simulated spring averaged monthly mean temperature and precipitation in southwestern North America for RCP8.5. Changes are between the present day and 2100, with five years representing each time period. The color bar is reversed for precipitation, with redder colors indicated drier conditions.

Evaluation of dust emissions based on LPJ-LMfire

Figure S2 shows the simulated present-day (2011-2015) distribution of VAI over the southwestern U.S. Values are derived from LAI generated by the LPJ-LMfire dynamic vegetation model. We find relatively high VAI values in central Arizona, northern New Mexico, northern Texas, and northwestern Mexico, but near-zero VAI in the arid regions of western Texas and along the northern Mexico border. Correspondingly high dust emissions are simulated over these areas in spring.

We apply these emissions to GEOS-Chem and evaluate the resulting fine dust concentrations using ground-based measurements from the Interagency Monitoring of Protected Visual Environments (IMPROVE) network (Malm et al., 2004). Hand et al., 2016 used the observed iron content from IMPROVE as a proxy for fine dust concentrations, and approximated soil-derived $PM_{2.5}$ as $PM_{2.5}$-Iron/0.058. IMPROVE dust observations are made every three days, and we show the spatial or temporal median of these observations as outliers are common in the dataset, and GEOS-Chem is unlikely to capture the extreme dust events. For model validation, we rely on the RCP8.5 results for 2011-2015, which yields nearly identical results as RCP4.5. GEOS-Chem tracks fine dust with a diameter range of 0.2-2.0 μm, while the IMPROVE approximation yields dust concentrations with diameter less than 2.5 μg m^{-3}. This disparity may hinder the model comparison with observations.

Figure S3 compares the spatial distribution of GEOS-Chem springtime dust concentrations with observations, and Figure S4 examines the temporal variability of modeled and observed dust averaged over the region. In general, the model captures both the observed spatial and temporal variability, though GEOS-Chem underestimates dust at a few sites in Arizona. This underestimate could be a result of abundant mountain vegetation simulated by LPJ that alleviates dust generation from persistently arid or desert regions. The 2011-2015 timeseries of observed and modeled dust (Figure S4) reveals that GEOS-Chem exhibits a smaller seasonal variation of 0.2-3.1 μg m^{-3}, compared with the observed range of 0.2-8.1 μg m^{-3}. Overall, we find that the present-day simulations reasonably reproduce observed fine dust over southwestern North America.

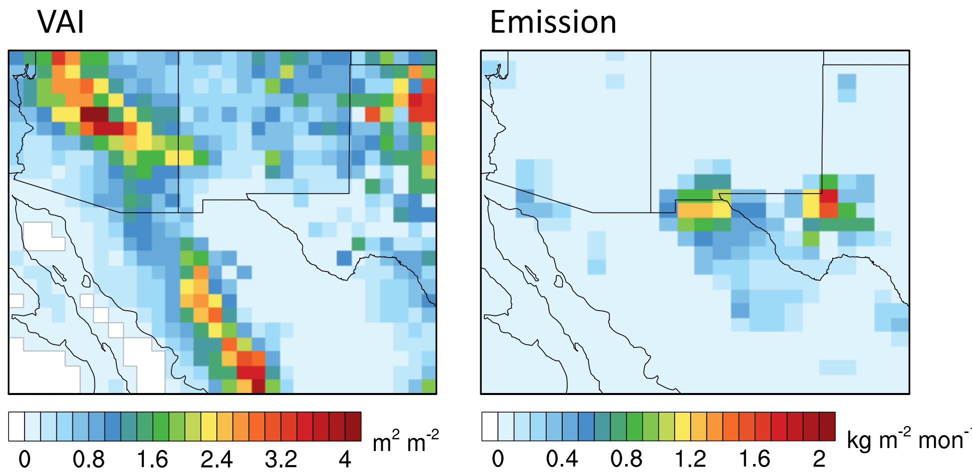

Figure S2. Present-day (2011-2015) spring averaged VAI and fine dust emissions for the RCP8.5 fixed-CO_2 scenario in southwestern North America, in which CO_2 fertilization is neglected. VAI results are from LPJ-LMfire. Dust emissions are generated offline using the GEOS-Chem emission component (HEMCO).

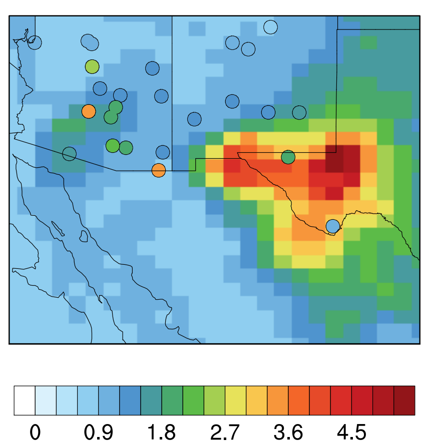

Figure S3. Spring fine dust concentration. Circles represent ground-based observations from the IMPROVE network, shown as the medians at each site over 2011-2015. The colored background is from GEOS-Chem simulations with the present-day (2011-2015) fine dust emissions for the RCP8.5 fixed-CO_2 scenario at 0.5° x 0.625° spatial resolution.

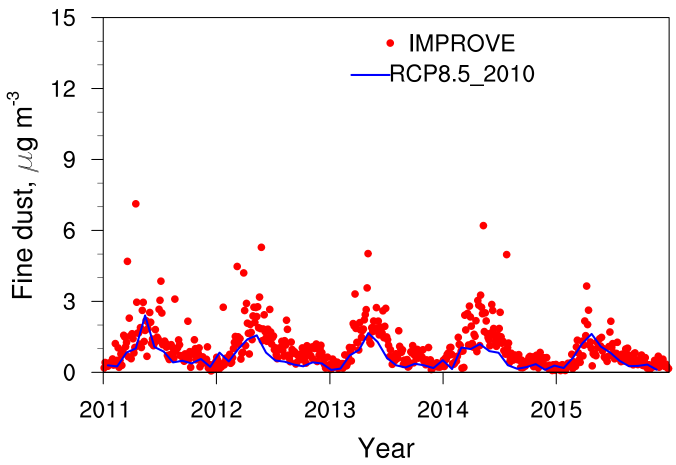

Figure S4. Seasonal cycle of GEOS-Chem simulated and IMPROVE observed fine dust concentrations, shown as the medians over southwestern North America from 2011 to 2015. The red dots represent the median of IMPROVE observations taken over all sites in the region at each measurement timestep. IMPROVE has a measurement frequency of every three days. The solid line shows GEOS-Chem simulated variations at 0.5° x 0.625° resolution for the 2010 time slice for the RCP8.5 fixed-CO_2 scenario.

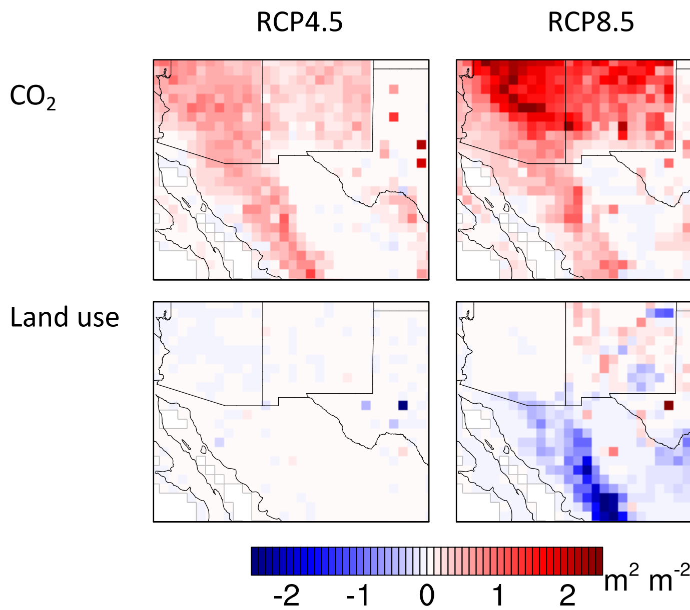

Figure S5. Contributions of CO_2 fertilization and anthropogenic land use to changes in VAI in spring in southwestern North America for RCP4.5 and RCP8.5. Changes are between the present day and 2100, with five years representing each time period. The top row is for CO_2 fertilization, and the bottom row is for land use trends. Results are from LPJ-LMfire.

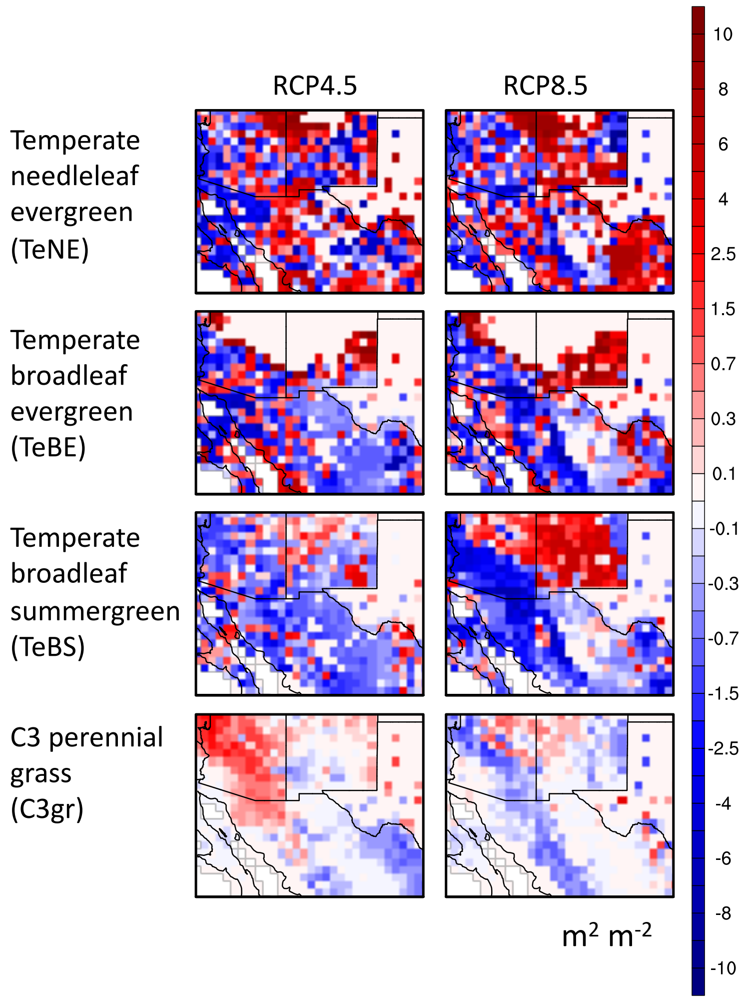

Figure S6. Simulated changes in springtime averaged LAI for the four dominant plant functional types (PFTs) in southwestern North America under RCP4.5 and RCP8.5 for the fixed-CO_2 condition, in which CO_2 fertilization is neglected. Changes are between the present day and 2100, with five years representing each time period. Increments in the color bar are unevenly distributed. Results are from LPJ-LMfire.

References

Hand, J., White, W., Gebhart, K., Hyslop, N., Gill, T., and Schichtel, B.: Earlier onset of the spring fine dust season in the southwestern United States, Geophysical Research Letters, 43, 4001-4009, 2016.

Malm, W. C., Schichtel, B. A., Pitchford, M. L., Ashbaugh, L. L., and Eldred, R. A.: Spatial and monthly trends in speciated fine particle concentration in the United States, Journal of Geophysical Research: Atmospheres, 109, 2004.