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Developing emulators of regional climate responses to regional aerosol perturbations using three coupled chemistry-climate models

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The climatic implications of regional aerosol and precursor emissions reductions implemented to protect human health are poorly understood. However, quantitative estimates of climate responses to emission perturbations are needed by the climate assessment and impacts community. To address this need, we investigate the global and regional mean climate response to regional changes in aerosol emissions using three coupled chemistry-climate models: NOAA GFDL-CM3, NCAR-CESM1, and NASA GISS-E2. Our approach contrasts a long present-day control simulation from each model (up to 400 years with perpetual year 2000 or 2005 emissions) with fourteen individual aerosol emissions perturbation simulations (160-240 years each). We perturb emissions of sulfur dioxide (SO_2) and/or carbonaceous aerosol within six world regions and assess the statistical significance of temperature and precipitation responses relative to internal variability determined by the control simulation and across the models. Using the three models and their statistical significance as an indicator of robustness of climate responses to aerosols, we develop emulators of the climate response to changes in aerosol emissions. Emulators are defined as the change in a climatic variable (e.g. temperature) in a region i normalized by the change in emissions and/or radiative forcing for species S in region j, i.e. $dT_i/dE_{j,S}$, where T is temperature and E is emissions. In all models, the emulators for global mean surface temperature response (perturbation minus control) to aerosol is positive (warming). Results also indicate that the Arctic is the most sensitive region to nonlocal aerosol emissions or forcing, as the emulators are largest for the Arctic. Emulator calculations indicate a robust regional response to aerosol emissions or forcing within the northern hemisphere mid-latitudes, regardless of where the aerosol forcing is located longitudinally. We assess the utility of our emulators by applying them to an ensemble of historical and future CESM simulations in which anthropogenic aerosol emissions are removed to isolate the climate response to aerosols. We find good agreement between the ensemble mean temperature response to aerosols as simulated by CESM and the reconstructed temperature response from the emissions-based emulators and the emissions input to CESM. This work is a first step towards providing statistical relationships between the changes in regional aerosol emissions and the statistically significant changes in climate that can be attributed to them. Such relationships would allow for the generation of regional climate change scenarios without having

to simulate computationally demanding chemistry-climate models.