Quantifying Feedbacks of Climate Intervention under Climate Change

Forrest M. Hoffman (hoffmanfm@ornl.gov), Min Xu (xum1@ornl.gov), Wei Zhang, Salil Mahajan, and Xiaojuan Yang (Oak Ridge National Laboratory, Oak Ridge, TN, USA)
Cheng-En Yang (cyang10@utk.edu) (University of Tennessee, Knoxville, TN, USA)

Background/Objectives. The increasing severity of the effects of anthropogenic climate change, especially strengthening extreme events and large-scale wildfire, is threatening built infrastructure, utilities, and national and economic security. Loss of life and property is motivating serious consideration of approaches for climate intervention or geoengineering. In addition to efforts to scale up carbon dioxide removal (CDR) through direct air capture (DAC) and other means, achieving net zero emissions through enhanced carbon uptake and sequestration, interest is growing in methods to reduce or stabilize Earth's surface temperature. One approach to partially reduce warming is solar radiation management (SRM), which would reflect a portion of incoming solar radiation, thereby increasing the planetary albedo, cooling Earth's surface, and maintaining resilience of the Earth system. Stratospheric aerosol intervention (SAI), through direct injection of sulfur into the lower stratosphere, is considered the most feasible scheme that would have a significant impact on surface temperature. While global climate modeling studies have shown that such SAI would likely reduce surface temperatures and partially ameliorate the temperature-driven effects of climate change, many questions remain unanswered regarding the feedback effects of SAI on the entire Earth system.

Approach/Activities. To fill the nationally recognized research gap in understanding the potential Earth system feedbacks of SAI on ecosystems, regional atmospheric circulation, and biogeochemical cycles, a series of increasingly complex geoengineering simulations, using DOE's Energy Exascale Earth System Model (E3SM), that mimic the effects of CDR, SAI, and CDR plus SAI in combination, should be conducted and analyzed. The integrated effects of CDR and SAI on a changing climate, including a non-catastrophic path to SAI termination, have yet to be investigated in a fully coupled process-based Earth system model. Thus, to address contrasting effects of SAI on scenarios involving CDR, researchers could start with the well-defined SSP5-3.4-OS mid-range overshoot CO_2 trajectory from the Coupled Model Intercomparison Project (CMIP), which prescribes an drawdown of atmospheric CO_2 due to CDR, large reductions in emissions, or both. In that scenario, global surface temperatures rise by >2.5°C around 2040, well above the 2°C threshold that may induce irreversible impacts. Thus, a second set of simulations would introduce SAI to simultaneously cool the surface, or "shave" the temperature peak, until drawdown is sufficient to assure <2°C warming. These and other scenario simulations must be analyzed to determine the effects of reduced radiative forcing despite increasing atmospheric CO_2 levels on Earth's climate, regional atmospheric dynamics and aerosol-cloud interactions, and terrestrial and marine carbon sink strengths.

Results/Lessons Learned. Aside from reducing incoming radiation, partially shifting radiation from direct to diffuse, suppressing precipitation in some regions, and potentially increasing acidification of inland water bodies, little is known about the impacts of SAI on Earth's terrestrial and marine ecosystems, regional atmospheric circulation, and marine and atmospheric chemistry. Initial research by some of the authors indicates a potential benefit of increased terrestrial biosphere uptake due to sustained CO_2 fertilization effects and lack of additional warming from partially coupled Earth system model simulations. A 2021 consensus study report from the National Academies of Sciences, Engineering, and Medicine (NASEM) recommends that research be conducted to better characterize and reduce scientific and societal uncertainties concerning the benefits and risks of [solar geoengineering] SG deployment, so that informed decisions can be made in the future about possible implementation.