Ph.D. Defense Announcement
Kimberley Corwin
Monday, June 10, at 10:00 am

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Ph.D. Defense

June 10, 2024
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Defense
ATS Large Classroom (101 ATS) or Teams

Post Defense Meeting
Riehl Conference Room (211 ACRC)

Committee:
Emily Fischer (Advisor)
Jeffrey Pierce
Christine Chiu
Chelsea Corr-Limoges (Springfield College)
Jesse Burkhardt (Agricultural and Resource Economics)

CHANGES IN SHORTWAVE SOLAR RADIATION UNDER LOCAL AND TRANSPORTED WILDFIRE SMOKE PLUMES: IMPLICATIONS FOR AGRICULTURE, SOLAR ENERGY, AND AIR QUALITY APPLICATIONS

The emission and transport of pollutants from wildfires is well-documented, particularly at the surface. However, smoke throughout the atmospheric column affects incoming shortwave solar radiation with potentially wide-ranging consequences. By absorbing and scattering light, smoke changes the amount and characteristics of shortwave radiation–a resource that controls plant photosynthesis, solar energy generation, and atmospheric photochemical reactions. In turn, these influence ecological systems as well as air quality and human health. This dissertation examines how wildfire smoke alters boundary layer and surface-level shortwave radiation in ways that are relevant for agricultural, energy, and air quality applications.

First, I present an analysis of smoke frequency and smoke-driven changes in the total and diffuse fraction (DF) of photosynthetically active radiation (PAR; 400-700 nm) at the surface. I compare PAR and PAR DF on smoke-impacted and smoke-free days during the agricultural growing season from 2006 to 2020 using data from 10 ground-based radiation monitors and satellite-derived smoke plume locations. I show that, on average, 20% of growing season days are smoke-impacted and that smoke prevalence has increased over time ($r = 0.60$, $p < 0.05$). Smoke frequency peaks in the mid to late growing season (i.e., July, August), particularly over the northern Rocky Mountains, Great Plains, and Midwest. I find an increase in the distribution of PAR DF on smoke-impacted days, with larger increases at lower cloud fractions. On clear-sky days, daily average PAR DF increases by 10 percentage points when smoke is present. Spectral analysis of clear-sky days shows smoke increases DF (average: +45%) and decreases total irradiance (average: −6%) across six wavelengths measured from 368 to 870 nm. Optical depth measurements from ground and satellite observations both indicate that spectral DF increases and total spectral irradiance decreases with increasing smoke plume optical depth. My analysis provides a

foundation for understanding smoke's impact on PAR, which carries implications for agricultural crop productivity under a changing climate.

Second, I examine smoke's impact on two key measures used to assess a location's baseline solar resource availability for solar energy production: direct normal (DNI) and global horizontal (GHI) irradiance. I quantify smoke-driven changes in DNI and GHI at different spatial and temporal scales across the contiguous U.S. (CONUS) using radiative transfer model output and satellite-based smoke, aerosol, and cloud observations. Importantly, I expand the scale of previous studies on smoke and solar energy by including areas primarily affected by dilute, aged, transported smoke plumes in addition to areas with dense, fresh, local smoke plumes. I show that DNI and GHI decrease as smoke frequency increases at the state, regional, and national scale. DNI is more sensitive to smoke with sizable losses persisting downwind of fires. Although large reductions in GHI are possible close to fires, mean GHI declines minimally (< 5%) due to transported smoke. Overall, GHI– the main resource used for photovoltaic energy production–remains a relatively stable resource across most of CONUS even in extreme fire seasons, which is promising given U.S. solar energy goals.

Third, I investigate smoke-driven changes in surface-level and boundary layer downwelling actinic flux (F↓)–a crucial component of determining the rate of photooxidation in the atmosphere. I present a case study of changes in F↓ at 550 nm (process validation) and 380 nm (NO2 photolysis) along a research flight through the California Central Valley during the 2018 Western Wildfire Experiment for Cloud Chemistry, Aerosol Absorption, and Nitrogen (WE-CAN) aircraft campaign. F↓ was measured onboard via the HIAPER Airborne Radiation Package (HARP), and I use the National Center for Atmospheric Research (NCAR) Tropospheric Ultraviolet and Visible (TUV) Radiation Model to compute F↓ under smoke-free and smoke-impacted conditions. Modeling F↓ with TUV facilitates calculating the change in F↓ and provides a means of assessing F↓ at altitudes not sampled by the aircraft, such as the ground. I find that the smoke-impacted F↓ from TUV aligns closely with HARP observations: all modeled fluxes are within 20% of measurements at 550 nm and 87% are within 20% of measurements at 380 nm. The average modeled-to-measured ratios (F↓_550=0.96; F↓_380=0.89) indicate that TUV minorly underestimates the observed F↓. On average, observed F↓380 decreased 26%, 17%, and 9% at 0-0.5 km, 0.5-1 km, and 1-1.5 km, respectively, while TUV estimates larger reductions of 41%, 25%, and 19% at the same altitudes. At the ground-level, I calculate a 46% decrease in F↓380 using TUV, which is likely an upper bound given the model slightly underestimates observations. As wildfire smoke increases with climate change, understanding how smoke aloft changes photochemistry is increasingly important for constraining future air quality.