**Integrating observations and process-oriented diagnostics to constrain aerosol-cloud interactions in Earth system model development**

Adam Varble and Po-Lun Ma

Pacific Northwest National Laboratory

The effective radiative forcing by aerosol-cloud interactions (ACI) in liquid clouds is one of the largest uncertainties in climate models, contributing greatly to the spread in future climate predictions. E3SMv1 produces a strong forcing but the causes are unclear. Motivated by the need to better integrate ACI observational constraints and process understanding into model development, we have begun development of a new Python-based liquid cloud ACI diagnostics package compatible with E3SM output that will eventually extend to variable resolution output and other climate models. We incorporate satellite retrievals from multiple sources with DOE Atmospheric Radiation Measurement (ARM) measurements to evaluate relevant E3SM aerosol, cloud, meteorology, and radiation variable probabilities, joint distributions, and diurnal and seasonal cycles. Initial comparisons show that E3SMv1 accurately reproduces ARM Eastern North Atlantic site surface cloud condensation nuclei (CCN) distributions and diurnal cycles of CCN and cloud coverage. Significant differences include smaller cloud droplet effective radii, lesser cloud fraction, excessive drizzle, weaker inversion strength, and incorrect dependence of cloud top effective radius on surface CCN and liquid water path in E3SMv1. We are investigating how insufficient treatments in cloud and aerosol parameterizations contribute to these differences. We demonstrate, for example, that overly small cloud droplets in E3SMv1 may be associated with excessive aerosol activation due to strong turbulence, and that weakening turbulence and increasing subgrid vertical velocity PDF skewness reduces this bias. Our new process-oriented diagnostics package for ACI will facilitate routine model evaluation during development, bridging the gap between process understanding and Earth system modeling.