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DOE's Research Activities Relevant to ERB

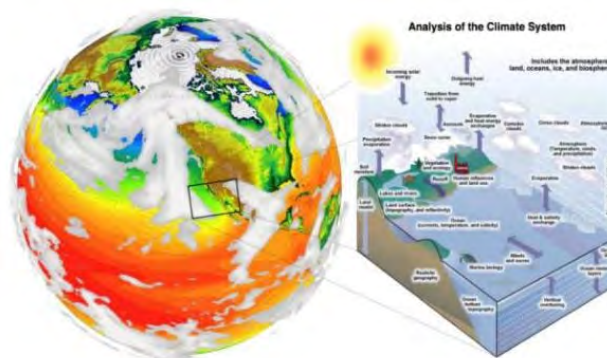
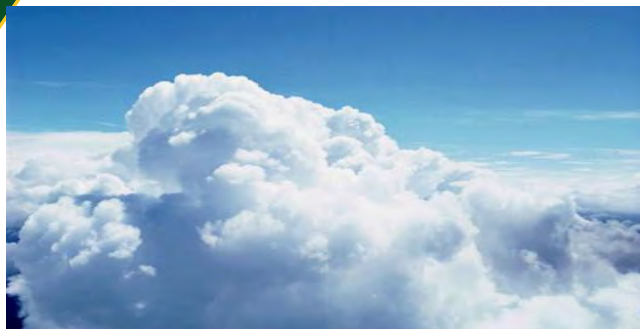
Dr. Sally McFarlane

Program Manager

Atmospheric Radiation Measurement (ARM)

User Facility

Earth and Environmental Systems Sciences Division



Atmospheric Science

- Atmospheric System Research (ASR)
- Atmospheric Radiation Measurement (ARM) User Facility

Earth and Environmental Systems Modeling

- Earth System Model Development
- Regional and Global Model Analysis
- Multisector Dynamics

Environmental System Science

- Watershed Sciences
- Terrestrial Ecology
- Coastal Systems
- Urban Integrated Field Labs
- Environmental Molecular Sciences Laboratory (EMSL)

Data Informatics



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<https://science.osti.gov/ber/Research/eessd>

ARM/ASR Overview & Relevant Activities



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Atmospheric Radiation Measurement (ARM) User Facility

- ▶ ARM is a DOE Office of Science user facility
- ▶ Long-term in situ and remote sensing observations of aerosol, clouds and radiation to improve the representation of their impacts on the energy budget in Earth system models
- ▶ 3 fixed measurement sites (Oklahoma, Alaska, Azores) in different climate regimes; 1 mobile facility for mid-range (~5 year) deployments
- ▶ 2 mobile facilities available for proposal-driven 6 mo. – 2 y deployments
 - ▶ e.g., the TRACER, EPCAPE, and CAPE-k campaigns
- ▶ 24/7 data collection at fixed/mobile facilities with all data freely available at www.archive.arm.gov
- ▶ High-performance computing resources for working with large ARM data sets
- ▶ Aerial facility component

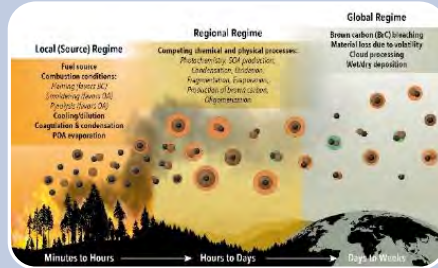


Atmospheric System Research Program (ASR)

ASR supports observational, data analysis, and/or modeling studies that use observations supported by BER – typically from the ARM facility and/or PI laboratories – to improve understanding and model representation of climate-relevant atmospheric processes.



Convective cloud processes and properties including cloud cover, precipitation, life cycle, dynamics, and microphysics over a range of spatial scales.



Aerosol processes governing the spatial and temporal distribution of atmospheric particles and their chemical, microphysical, and optical properties.



High latitude processes including cloud, aerosol, and surface-interaction processes controlling the surface energy budgets in northern and southern high latitude regions



Warm boundary-layer processes controlling the structural and radiative properties of clouds, aerosols and their interactions with the underlying surface in the lowest few kilometers of the atmosphere.

ARM/ASR Activities Relevant to ERB Goals (1)

- ▶ ASR-funded research on warm boundary layer processes and aerosol-cloud interactions at DOE labs and universities
- ▶ ARM sites and mobile facility deployments:
 - ▶ Eastern North Atlantic (ENA) fixed site
 - ▶ ARM routine LES simulations being developed
 - ▶ EPCAPE – Eastern Pacific Cloud Aerosol Precipitation Experiment
 - ▶ ARM Mobile Facility located on Scripps Pier; additional measurements on Mt Soledad
 - ▶ Past campaigns (MAGIC, ACAPEX, LASIC)



ARM/ASR Activities Relevant to ERB Goals (2)

- ▶ Co-sponsored MCB workshop with NOAA
- ▶ NSF-ASR-funded cloud chamber research activity
- ▶ 2021-2022 PNNL pilot project on Aerosol Delivery: Boundary Layer Transport of Aerosols into Clouds – *now part of PNNL Science Focus Area*
- ▶ Upcoming workshop on Observing Marine Aerosols & Clouds from Ships
- ▶ ASR Links
 - ▶ Award descriptions: <https://asr.science.energy.gov/projects> (multiple PI-led projects focusing on aerosol-cloud interactions)
 - ▶ Research highlights: <https://asr.science.energy.gov/science/highlights>

Earth and Environmental System Modeling - Relevant Activities



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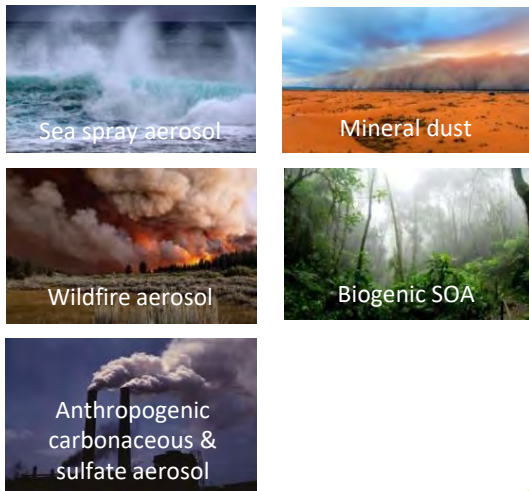
Enabling Aerosol-cloud interactions at GLocal convection-permitting scales (EAGLES)

Achieve unprecedented realism in predictions of the role of aerosol and aerosol-cloud interactions in the Earth system, through the combination of advancing fundamental science and utilizing modern data science and computational methods, to address critical challenges facing the nation and DOE.

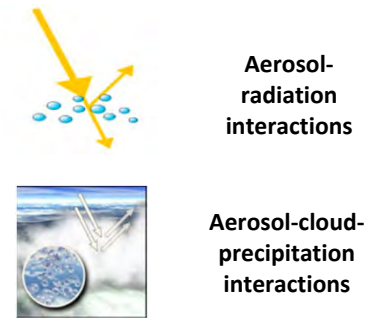
PI: Po-Lun Ma (PNNL)



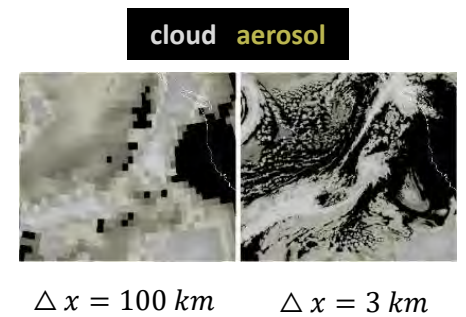
Improved representation of emission and chemical/physical processes



Improved representation of aerosol-radiation-cloud-precipitation interactions



Modern software for exascale computation on GPUs



Kilometer scale E3SM simulation of aerosol and aerosol-cloud interactions with C++/kokkos

Model development

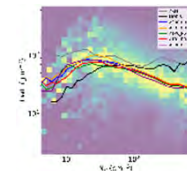
Model evaluation & analysis



Measurements



Process model and large eddy simulations



Process-oriented diagnostics

Interactive atmospheric chemistry for E3SMv3

Qi Tang (LLNL), Michael Prather (UCI)

New interactive chemistry enables E3SMv3 to calculate all greenhouse gas trajectories to support critical E3SM science simulations at a small fraction ($\sim 15\%$) of the overall computational cost.

New features to be in E3SMv3:

- Fully interactive chemistry: Strat - Linoz v3; Trop – chemUCI
- Fast-J photolysis links with aerosols and clouds
- New capabilities to represent gas chemistry tracers in the stratosphere and troposphere.
- More physical simulation of aerosol-cloud interactions with online chemistry.

Slide from Shaocheng Xie (LLNL)

Stratospheric O₃

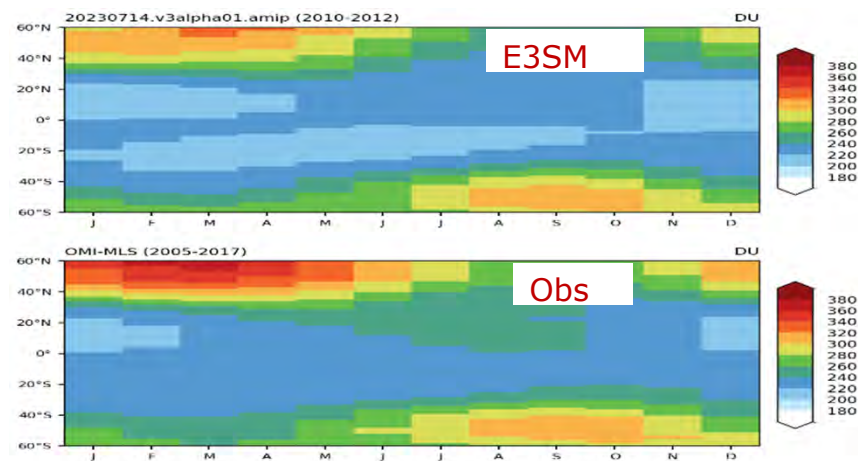
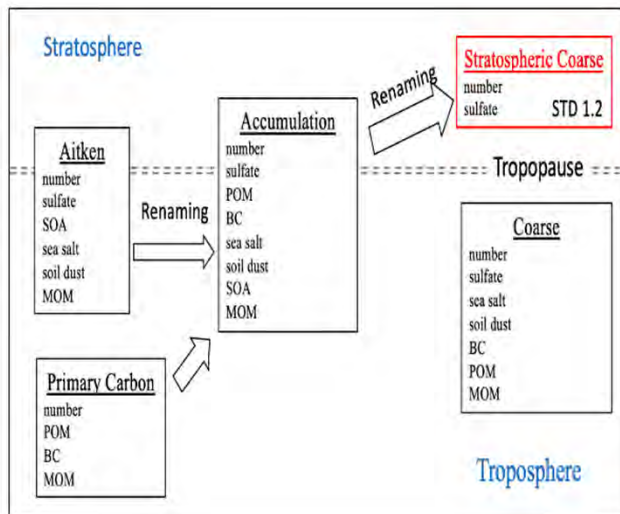


Figure: Historical strat O₃ zonal mean annual cycle (bottom) are well captured.

MAM5 for Stratosphere Sulfate Aerosol for E3SMv3

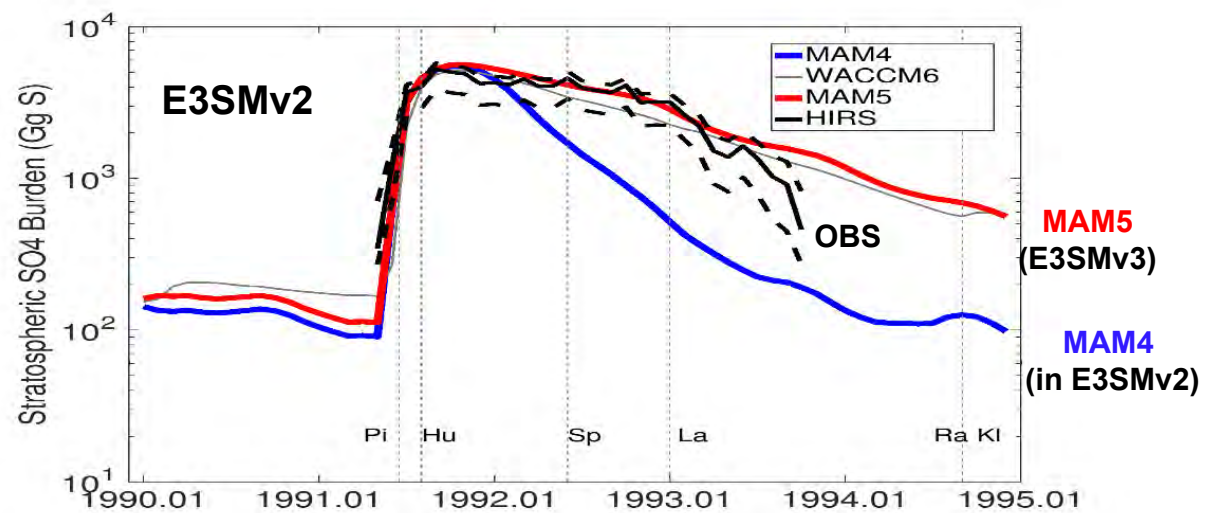
TAMU: Xiaohong Liu (PI); LLNL: Ziming Ke

Adding a new stratospheric coarse mode to represent sulfate aerosol from explosive volcanic eruptions. This new treatment improves the simulation of natural climate variability from E3SM



Adding **stratospheric coarse mode** to previous MAM4 (now **MAM5**)

Stratosphere Sulfate Aerosol Burden



Slide from Shaocheng Xie (LLNL)

Climate forcing an unaddressed uncertainty

Addressing volcanic aerosol forcing uncertainty

- Anthropogenic and natural aerosols strongly impact climate variability and change – their presence is uncertain prior to satellites (<1979)
- CMIP6-era stratospheric volcanic emission inventories omit $\sim 1 \text{ Tg SO}_2 \text{ yr}^{-1}$ before the satellite era, $\sim 7x$ very large 1991 Pinatubo eruption forcing missing per century
 - Pinatubo emitted 15 Tg SO_2 , cooling the planet by -0.3C
 - Large uncertainties exist for smaller eruption aerosol emissions, and their climate impacts
 - Underestimates time-averaged volcanic aerosol-forced cooling by $\sim 50\%$
 - Strong pre- vs post-1979 step change in CMIP6 volcanic forcing, impacts model variability/change
- CMIP Forcing Task Team addressing this uncertainty
 - Account for all magnitude events, not just large eruptions ($>10 \text{ Tg SO}_2$)
 - Evaluate next-generation forcing through prototype climate model simulations - publish to CMIP6Plus project for community assessment
 - Publish prototype and final datasets to input4MIPs, for CMIP7 use in preparation for IPCC AR7
 - Develop uncertainty estimates for climate model response and sensitivity studies



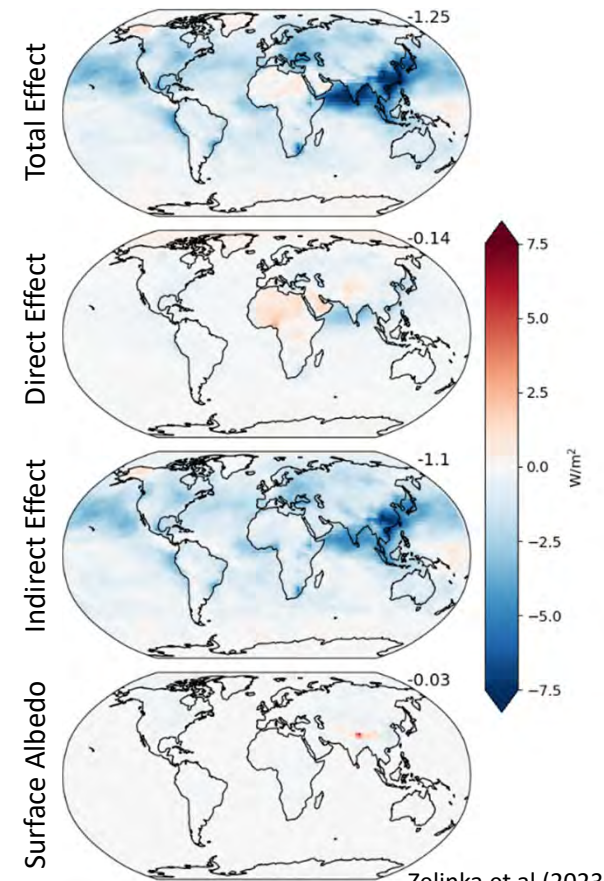
Effective Radiative Forcing from Aerosols: Direct and Indirect Effects

Novel diagnostic techniques

- We have developed techniques for easily quantifying the aerosol effective radiative forcing and all of its sub-components:
 - **Direct effects:** aerosol impacts on **scattering** and **absorption** of radiation
 - **Indirect effects:** aerosol impacts on cloud **amount**, **scattering**, and **absorption** of radiation
 - **Effects on surface albedo**
- *Applications: estimating the radiative impact of marine cloud brightening, stratospheric aerosol injections, or surface albedo enhancement*

Model experimentation

- We have built a perturbed physics ensemble with the E3SMv2 climate model to explore dependence of aerosol forcing on model parameters.
- *Applications: understanding how and why aerosol direct and indirect effects depend on parameter choices and mean climate state*



Zelinka et al (2023)

DOE Upcoming Opportunities

- ▶ ASR Funding Opportunity Announcement
 - ▶ DE-FOA-0003194
 - ▶ <https://asr.science.energy.gov/news/program-news/post/17625>
 - ▶ Topics include aerosol processes at ARM sites; convective cloud processes; **aerosol and cloud processes from ARM's Eastern Pacific Cloud Aerosol Precipitation Experiment (EPCAPE)**; mixed-phase cloud and ice cloud processes
- ▶ ARM Mobile Facility solicitation
 - ▶ ARM will be releasing call for proposals for deployment of the ARM Mobile Facilities in 2026
 - ▶ <https://arm.gov/research/campaigns>
- ▶ Earth and Environmental System Modeling
 - ▶ Expects to release an FOA for FY24 funding in late fall