LLNL-TR-837728

LAWRENCE LIVERMORE NATIONAL LABORATORY

The Early Career Research Program Annual Progress Report:Using ARM Data and Multiscale Models to Advance the Understanding of Liquid-Phase Cloud Response to Aerosol Perturbation over Ocean and Land

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July 20, 2022

Disclaimer

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

ECRP: Annual Progress Report

Using ARM Data and Multiscale Models to Advance the Understanding of Liquid-Phase Cloud Response to Aerosol Perturbation over Ocean and Land

July 31, 2022

Award number: SCW1740
Project period: 2021-2026
Budget period: FY2022

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Abstract

This report is for the first fiscal year of this ECRP project. This ECRP project aims to study the response of liquid-phase clouds to aerosol perturbation and reduce the related uncertainty in the DOE Earth system model.

During this fiscal year, this project mainly made progress on the tasks about observational analyses for Objective 1; and successfully set up two Large-Eddy Simulation (LES) models for Objective 2. A postdoctoral researcher and a graduate student summer intern are on board and fully dedicated to this project. In addition to internal collaboration within LLNL, this project has routinely maintained external collaboration with scientists from universities, NASA Langley Research Center, and other DOE national laboratories.

For the next reporting period, we plan to complete the tasks scheduled for the second year. Furthermore, we will promote the findings to communities of interest and proactively seek new collaborations to increase the impact of this project.

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Accomplishments

1. What are the major goals of the project?

This project aims to:

1) Use ARM observational data and satellite retrievals to estimate the observational aerosol indirect effect on liquid-phase clouds.

2) Conduct observationally constrained large-eddy simulations (LES) to study how the small-scale cloud responses lead to a net radiative forcing of aerosol-cloud interactions at scales relevant to the current Earth system models.

3) To reduce model biases related to aerosol indirect effect in the DOE Energy Exascale Earth System Model (E3SM) configurations.

2. What was accomplished under these goals?

For the first year of this project, we mainly made progress on the tasks about observational analyses for the first goal and set up two Large-Eddy Simulation (LES) models for the second goal. We analyzed the aerosol influence on northeastern Atlantic cloud properties with a focus on the ARM ENA site.

We identified the signal of the aerosol brightening (i.e., Twomey effect) and drying (negative LWP susceptibility) effects from the Meteosat-11 4km pixel-level cloud retrievals over the ENA region. Furthermore, the multi-linear regression analysis (Figure 1.) confirms that the observed positive response of cloud albedo to aerosols is mainly from the reduced droplet size while partly canceled by the negative LWP response.

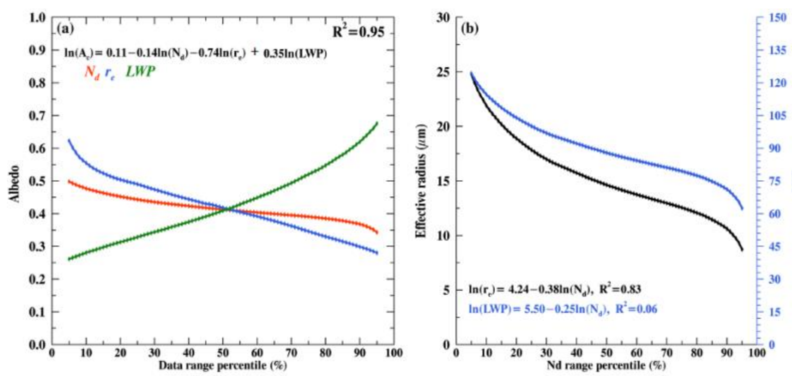

Figure 1. (a) Predicted change of cloud albedo over a 1°×1° centered at the ARM ENA site by varying each predictor with the multi-linear regression model based on Meteosat-11 cloud retrievals. (b) Predicted change in effective radius (black line) and LWP (blue line) with N_d.

Our ongoing regime-specific study with ERA5 reanalysis and ARM observations tested different clustering methods. We found that K-Means clustering with multiple large-scale variables can generate clusters well related to ARM observed cloud conditions (e.g., clusters related to low-cloud conditions in Figure 2). We are estimating aerosol and cloud microphysics co-variability within each regime to minimize the impacts of changes in large-scale cloud controlling factors.

In terms of numerical study, we successfully set up and tested SAM and WRF models for LES simulations on NERSC and LC. The boundary layer clouds at the ENA site are often driven by synoptic systems, such as post-frontal clouds during cold air outbreaks. To investigate the impact of realistic large-scale forcings on the simulated aerosol-cloud interactions relative to homogenous large-scale forcing in typical LES simulations, we added WRF nested-domain simulations of ACE-ENA cases. Consistent with the ACE-ENA observations, initial simulations (e.g., Figure 3) captured the large-scale circulation and cloud field in the coarse domain and the drizzling stratocumulus cloud in the inner domain. After improving the cloud top height in the inner domain through vertical grid nesting, we will start sensitivity tests with CCN perturbations in both nested-domain simulations and single-domain LES simulations.

Beside the ENA region, we have collected long-term ARM data, ERA5 data, and geostationary satellite retrievals in the Southern Great Plains (SGP) region for future analyses.

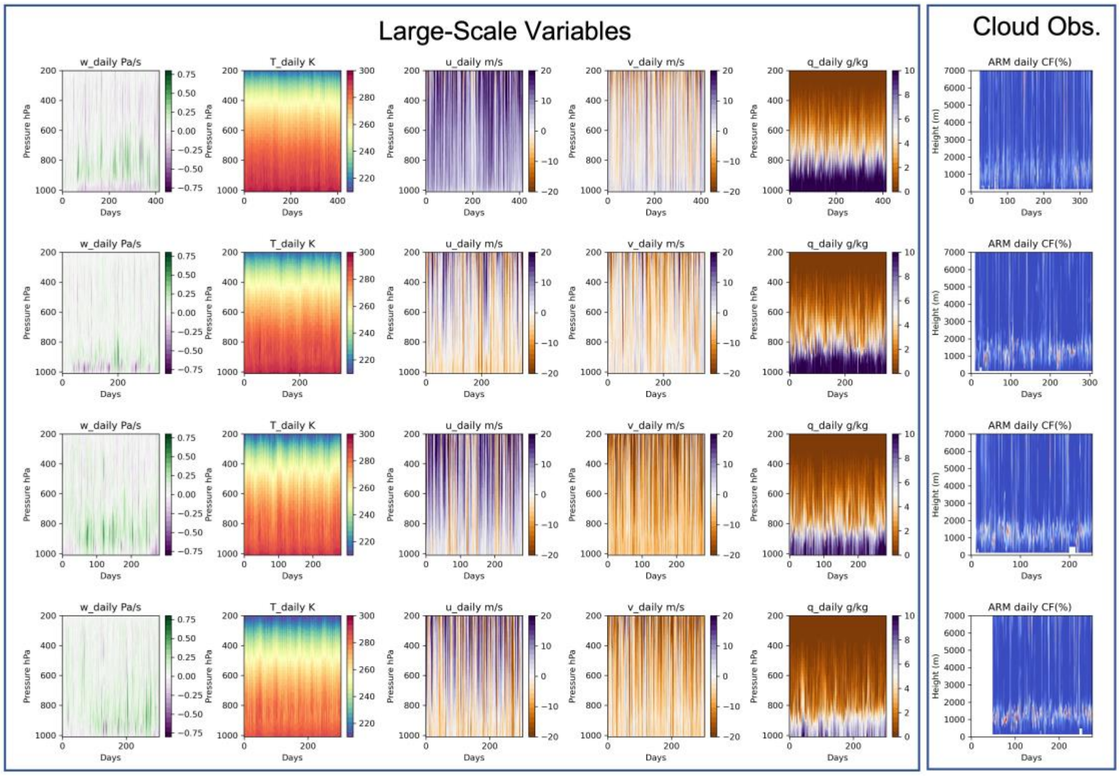

Figure 2. The daily large-scale variables (left) and the corresponded cloud fraction (right) for regimes mainly occurred in the summer (top two rows) and the winter (bottom two rows).

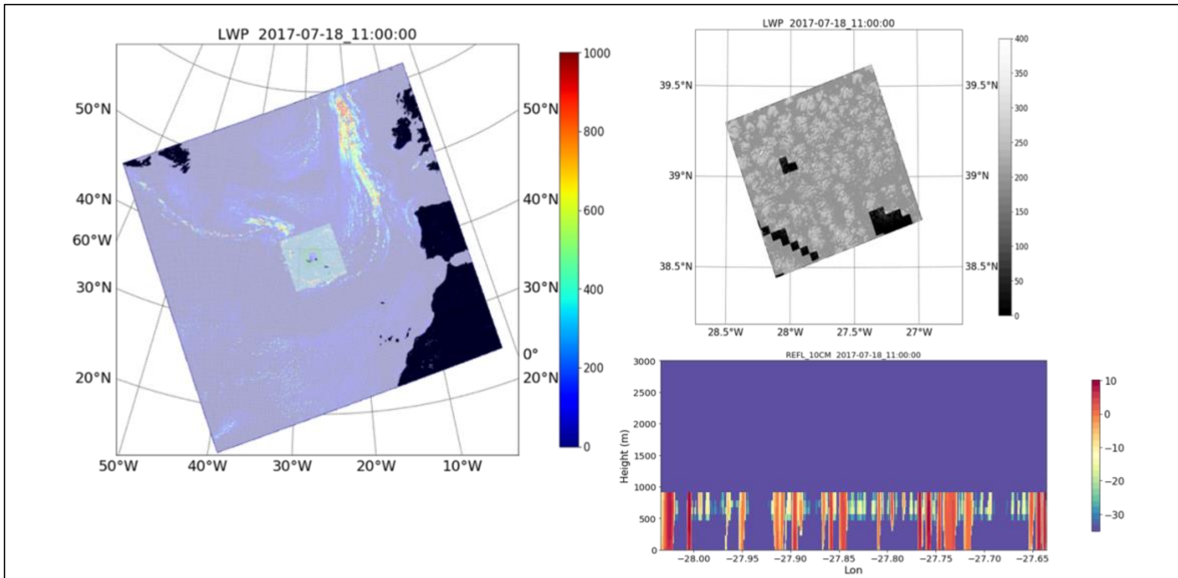

Figure 3. Snapshot of cloud LWP from nested domains (left), cloud LWP from the inner domain (top right), and curtain of simulated reflectivity at 10cm (bottom right).

3. What opportunities for training and professional development has the project provided?

This project funded a postdoctoral researcher and a graduate student summer intern. Dr. Shaoyue Qiu started in her postdoctoral position on 24 January 2022. She has been working on ARM ground-based observations and analyzing the aerosol indirect effect with satellite retrievals over the ENA region. A third-year Ph.D. student, Oumaima Lamaakel from the University of Connecticut, worked as a summer intern on the observationally constrained LES from the ACE-ENA field campaign. This project also provided PI with opportunities for mentorship, research collaboration, project management, and subcontract management.

4. How have the results been disseminated to communities of interest?

Given the early stage of this project, we have been mainly sharing our initial results with our collaborators and their research group. As we gain more conclusive results, we will seek opportunities to promote our findings by attending conferences and initiating new collaborations.

5. What do you plan on do during the next reporting period to accomplish the goals?

We plan to complete the tasks scheduled for the first and the second year. We will finish ARM data and satellite retrieval analyses for ENA and SGP regions by the end of the next fiscal year. And then, we will discuss the possible VAP with the ARM translator group. Furthermore, we will promote the findings to communities of interest and proactively seek new collaborations to increase the impact of this project.

Products – Details

1. Publications (including details such as journal, publication date, doi, authors, acknowledgement of DOE support, etc.)
2. Intellectual property
3. Technologies and techniques
4. Other products

Observational products:

1) ARM observations: hourly cloud and aerosol properties clustered by the large-scale conditions at the ENA site for 2016-2021.
2) Geostationary satellite retrievals: hourly susceptibility of cloud albedo and liquid water path to perturbations in cloud drop number concentration over the ENA region for 2018-2021.

Numerical simulations:

3) Initial LES simulations of a drizzling stratocumulus case on 18 July 2017 and a non-precipitating stratocumulus case on 6 July 2017 from the ACE-ENA field campaign with WRF and SAM models.
4) Initial WRF nested-domain simulations with horizontal resolutions from 5 km to 40 m for the ACE-ENA drizzling stratocumulus case on 18 July 2017.

Participants and Other Collaborating Organizations

1. Participants (including role, person months worked, description of contributions to the project, identification of international collaboration and travel)

PI Xue Zheng spent 12 months (~0.4 FTE) on this project. Besides managing the project, mentoring the postdoc and summer intern, and organizing collaborations with related projects and collaborators, PI conducted ARM observational analyses for the ENA site and set up LES models for the ACE-ENA case simulations. PI also managed a subcontract started on 01 July 2022 for advanced high-dimensional multivariate data clustering techniques and the evaluation matrix.

Shaoyue Qiu, our postdoctoral researcher, worked on this project for six months. Shaoyue collected and preprocessed observational data (e.g., long-term ARM data, satellite data, and ERA5 reanalyses over ENA and SGP regions) for this project. She analyzed the diurnal cloud variability and the cloud susceptibility to cloud drop number concentrations over the ENA region with the geostationary satellite retrievals.

Oumaima Lamaakel, our summer intern, worked on this project for 12 weeks. Oumaima created, conducted, and analyzed the LES simulations for two ACE-ENA cases.

There was no international collaboration and travel during this reporting period.

2. Partners (e.g., facilities support)

National Energy Research Scientific Computing Center (NERSC): NERSC awarded this project with 0.1M node hours and 20 TB CFS Storage between Jan 19, 2022, and Jan 18, 2023. All the observational data and related analyses are on NERSC machines. Most of the LES simulations conducted by Oumaima Lamaakel are on NERSC.

Livermore Computing (LC): LC provides this project with a free and stable HPC environment. This project conducted large-domain LES simulations on LC machines.

3. Other collaborations

We collaborated with Dr. David Painemal from NASA Langley Research Center for geostationary data quality and aerosol indirect effect. Another collaboration is Dr. Xiquan Dong from the University of Arizona and Dr. Virendra Ghate from Argonne National Laboratory for aerosol, cloud and precipitation properties derived from ARM ground-based measurements. We also collaborated with Dr. Zhibo Zhang from the University of Maryland, Baltimore County, for the observational study and LES simulations for the ACE-ENA field campaign.

Impacts

1. What is the impact on the development of the principal discipline(s) of the project?

We devoted most of our efforts to building the research team and initiating the research activities for the first year. We will promote the findings of this project to communities of interest and proactively seek new collaborations to increase our impact in the upcoming years.

2. What is the impact on other disciplines?
3. What is the impact of the development of human resources?
4. What is the impact on physical, institutional, and information resources that form infrastructure?
5. What is the impact on technology transfer?
6. What is the impact on society beyond science and technology?
7. Foreign spending

Nothing to report about the above questions.

Changes – Problems

1. Changes in the approach and reasons for change

We added WRF nested-domain simulations to investigate the impact of realistic large-scale forcings on the simulated aerosol-cloud interactions relative to homogenous large-scale forcing in typical LES simulations.

2. Actual or anticipated problems, delays and actions or plans to resolve them

It took several months for this project to hire a full-time postdoctoral fellow. The PI of this project required about three months to transition from previous projects to this project. As a result, this project has fallen behind schedule by ~4 months. We expect that we will be able to catch up with the original timeline during the second year of this project.

3. Changes that have a significant impact on expenditures

We hired a summer intern for the performance period 05/23/2022 - 08/13/2022 to speed up the progress on LES simulations. We started a subcontract with Dr. Jianwu Wang from the Department of Information Systems at the University of Maryland, Baltimore County, to advance our data clustering and evaluation techniques. The subcontract total award amount is $44,760 for the performance period 07/01/2022-05/31/2023. We are only incrementally funding it for now.

4. Significant changes in use or care of human subjects, vertebrate animals, and/or biohazards N/A
5. Change of primary performance site location from that originally proposed N/A
6. Carryover amount – *Note: please provide the full remaining carryover amount for the project, not just the current FY funds.*

The carryover from FY2021 into FY2022 was $450K. FY2022 funding is $500K. The estimated carryover at the end of FY2022 should be ~$600K.