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**Advancing the Understanding of Cloud Microphysical Processes and
Aerosol Indirect Effects in High-Latitude Mixed-Phase Clouds by Linking
ARM Measurements with Climate Model Simulations**

Final Report

Grant Number: DE-SC0021211

DOE/Office of Science Program Office: Climate and Environmental Sciences Division

Report Period: 09/01/2020 – 02/28/2025

Submitted on: June 7, 2025

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Abstract

The key objectives of this project were to advance our understanding of cloud microphysical characteristics and aerosol indirect effects on mixed-phase clouds in high latitudes. To improve the representation of ice and mixed-phase clouds in Earth System Models (ESMs), we propose an integrated observation and modeling study of cloud macro- and microphysical properties, including spatial heterogeneities, mass partitioning between ice crystals and supercooled liquid water, effects of ice nucleating particles (INPs), and efficiency of secondary ice production (SIP), etc.

Specifically, we took four main approaches in this project: (1) examining macro- and microphysical properties of ice and mixed-phase clouds based on in-situ and ground-based observations from multiple field campaigns funded by the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) program, including the Mixed-Phase Arctic Cloud Experiment (M-PACE), Indirect and Semi-Direct Aerosol Campaign (ISDAC), Ice Nucleating Particle Sources at Oliktok Point (INPOP), ARM West Antarctic Radiation Experiment (AWARE), Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean (MARCUS), and Macquarie Island Cloud and Radiation Experiment (MICRE); (2) evaluating the DOE Energy Exascale Earth System Model (E3SM) simulations based on observations, particularly for ice and mixed-phase cloud microphysical properties; (3) examining the impacts of INPs on ice and mixed-phase clouds. Specifically, a series of comparisons were conducted using observations over the Arctic, Southern Ocean, and Antarctica, including comparisons between the lower and higher southern latitudes as well as comparisons between the northern and southern hemispheres. In addition, aerosol indirect effects from distinct sources of dust particles were examined; and (4) investigating the impacts of SIP. Ultimately, these results helped to improve cloud microphysics and aerosol-cloud interaction parameterizations in the E3SM model.

Overall, the project provided improved understanding regarding various factors, including thermodynamic, dynamic, and aerosol conditions, on the micro- and macrophysical properties of ice and mixed-phase clouds in the high latitudes. Resulting analysis helped to provide an improved physical basis for refining the current cloud microphysics parameterizations related to ice and mixed-phase clouds in E3SM.

1. Objectives, Approaches Used, and Findings

1.1 Objectives of the project

The main objectives of this project are: (1) Advancing the understanding of key factors controlling ice and mixed-phase cloud characteristics, including thermodynamic, dynamical and aerosol indirect effects; (2) Evaluating DOE E3SM model parameterizations below 0°C, including cloud macro- and microphysical properties, aerosol indirect effects, and secondary ice production processes; (3) Quantifying impacts of ice nucleating particles (INPs) on ice and mixed-phase clouds, and tracing the high-latitude dust INPs originated from various geographical locations; (4) Examining various mechanisms for secondary ice production (SIP) processes (e.g., rime splintering, ice-ice collision fragmentation, and droplet shattering during freezing), and their impacts on cloud microphysical properties and radiative effects using an Earth system model.

1.2 Approaches used

We developed a series of approaches to enable examinations of cloud and aerosol processes and the key factors across a wide range of scales. The **key approaches** are as follows:

- (1) Derive a series of quantifiable cloud properties based on bottom-up remote sensing measurements from either ground-based (e.g., M-PACE, MICRE, AWARE) or ship-based (e.g., MARCUS) observations. These field observations were supported by the ARM program. The raw data include variables such as radar reflectivity from a cloud radar and depolarization ratio from a lidar, yet other cloud properties such as cloud thermodynamic phase, cloud top/base height, required further algorithm to retrieve. We provided PI value-added products (VAP) for these campaigns as demonstrated in several publications.
- (2) Develop a composite dataset using multiple airborne field campaign observations to examine cloud microphysical properties, as well as the individual effects of aerosol indirect effects, and thermodynamic and dynamic conditions. A large in-situ observational dataset allows a large sample size to isolate individual effects, especially since aerosol indirect effects are not as strong as the other thermodynamic/dynamic effects.
- (3) Develop several scale-aware, definition-aware comparison methods to enable meaningful comparisons between ARM observations and Earth system model simulations, across scales from hundreds of meters to hundreds of kilometers.
- (4) Incorporate new model parameterizations of secondary ice production (SIP) processes in the E3SM model.
- (5) Mentor two postdoctoral researchers, several graduate students, and one undergraduate student, and all of them had at least one first-author journal publication.
- (6) PI Diao and Co-I Liu served on multiple committees, hosted conference sessions, and disseminated results to the research community.

1.3 Key findings

(1) To quantify the effects of thermodynamic and dynamic conditions on Southern Ocean and Antarctic clouds, we examined the cloud macrophysical properties (e.g., cloud fraction) and microphysical properties (e.g., phase partitioning) through a wide range of latitudes over the Southern Ocean, as well as fixed locations on Macquarie Island and the McMurdo station.

By using the observations from the DOE ARM AWARE campaign, comparative analysis between observational data from McMurdo Station, Antarctica and the Community Atmosphere Model version 6 (CAM6) simulation was performed focusing on cloud characteristics and their thermodynamic conditions (Yip, Diao et al., 2021). Our findings show that the CAM6 simulation consistently overestimates (underestimates) cloud fraction above (below) 3 km in four seasons of a year. The cloud fraction biases are closely associated with concurrent biases in relative humidity (RH). Frequencies of correctly simulating ice and liquid-containing phase increase when the absolute biases of RH decrease. Water vapor mixing ratio biases are the primary contributor to RH biases, and hence, likely a key factor controlling cloud biases.

By using the DOE ARM MARCUS field campaign, we classified eight categories of hydrometeors (ice, liquid, mixed phase, rain, drizzle, snow, aerosols, and clear sky) based on measurements of lidar, radar and radiosondes (Desai, Diao et al., 2023). We found that two unique features of cloud vertical structure that depend on the latitudes – at the lower southern latitudes, clouds have ice phase cloud top followed by supercooled liquid layer below; while at the higher southern latitudes, clouds have a thin liquid-topped layer followed by a thicker ice layer below. Cloud thermodynamic phases (liquid, ice and mixed phase) at coarser scales were further derived to compare with the DOE Energy Exascale Earth System Model version 1 (E3SMv1) simulation and the Earth Model Column Collaboratory (EMC2) instrument simulator. The E3SMv1 underestimates cloud ice and overestimates cloud liquid at temperatures between -40°C and 0°C . Such model bias is unlikely caused by spatial scale differences or lack of heterogeneity in cloud vertical structure in the simulation. When evaluating a newer version of E3SM, the E3SM / EAMv2 simulations consistently show underestimation of ice phase frequencies in both Southern Ocean and Arctic regions (Desai, Diao et al., 2025).

By using DOE ARM MICRE and AWARE campaigns, we conducted a comparative study between lower and high southern latitudes and examined the influences of synoptic dynamical processes (Barone, Diao et al., 2024). A cyclone compositing method was used to quantify “dynamics-cloud-radiation” relationships relative to the extratropical cyclone centers. Observations show larger asymmetry in cloud and radiative properties between western and eastern sectors at McMurdo compared with Macquarie Island. When compared with the E3SMv1 simulations, ice water path (IWP) is consistently underestimated by the simulations at both locations, both sectors, and in all seasons. Biases of cloud fraction, LWP, and IWP are negatively correlated with SW biases and positively correlated with LW biases. The persistent negative IWP biases may have become one of the leading causes of radiative biases over the high southern latitudes, after correcting the underestimation of supercooled liquid water in the older model versions.

(2) To quantify the statistical distributions of cloud microphysical properties, including three thermodynamic phases, mass and number concentrations of ice crystals and supercooled liquid droplets, synchronized in-situ observations were examined (Yang, Diao et al., 2021). By using airborne observations from the NSF SOCRATES campaign, three climate models were evaluated, including DOE E3SMv1, NCAR CESM1/CAM6, and CESM2/CAM6. The E3SMv1 underestimates ice phase frequency below -20°C but overestimates it above -20°C . In addition, all models underestimate aerosol indirect effects on ice crystals and supercooled liquid droplets over the Southern Ocean.

To investigate the partition of supercooled liquid droplets and ice crystals during mixed-phase cloud evolution, we develop a novel method that differentiates between various phases of mixed-phase clouds, such as clouds dominated by pure liquid or pure ice segments, compared with those having ice crystals surrounded by supercooled liquid water droplets or vice versa (**Maciel, Diao et al., 2024**). The results show that the exchange between supercooled liquid water and ice crystals from a macrophysical perspective, represented by the increasing spatial ratio of regions containing ice crystals relative to the total in-cloud region (defined as ice spatial ratio), is positively correlated with the phase exchange from a microphysical perspective, represented by the increasing ice water content (IWC), decreasing liquid water content (LWC), increasing ice mass fraction, and increasing ice particle number fraction (IPNF). Larger aerosols were found to positively correlate with ice spatial ratio, which indicates that large aerosols potentially contain ice-nucleating particles (INPs), which facilitate the formation of ice crystals in mixed-phase clouds. By combining in-situ observations from multiple airborne campaigns (including DOE M-PACE, ISDAC, ACME-V and several NSF and NASA campaigns), we conducted a hemispheric comparison of the cloud phase distributions (**Yang, Diao et al., in review**). We found a higher frequency of supercooled liquid phase in the Southern Hemisphere at the same temperature compared with its Northern Hemisphere counterpart. Such hemispheric asymmetry was missing in the E3SMv1 simulations.

(3) To investigate the effects of SIP on ice and mixed-phase clouds, we quantified the contribution of SIP to the formation of ice in the Arctic mixed-phase clouds observed during M-PACE. We represented two new SIP mechanisms (i.e., shattering of frozen raindrops and ice-ice collisional breakup) in a global climate model (CESM2) and evaluated the CESM2 simulated clouds against the M-PACE observations (**Zhao et al., 2021; Zhao and Liu, 2022**). We found that the SIP is the dominant source of ice crystals near the cloud base for the Arctic single-layer mixed-phase clouds observed in M-PACE, with the maximum enhancement in ice crystal number concentrations by up to 4 orders of magnitude in moderately supercooled clouds (~ -10 °C), mainly through the frozen raindrop shattering. The SIP also competes with the primary ice nucleation by reducing the number concentrations of cloud droplets and cloud-borne dust INPs for immersion nucleation, highlighting the interaction between SIP and primary ice nucleation. The model with SIP improves the occurrence and phase partitioning of the single-layer mixed-phase clouds, reverses the vertical distribution pattern of ice number concentrations, and provides a better agreement with observations.

We assessed the global importance of SIP using the CESM2 model (**Zhao and Liu, 2021**). We found that SIP decreases the global annual mean liquid water path (LWP) by -14.6 g m^{-2} (-22%), increases the ice water path (IWP) by 8.7 g m^{-2} (23%), improving the model agreement with observations. SIP changes the global annual mean shortwave, longwave, and net cloud forcing by 2.1 , -1.0 , and 1.1 W m^{-2} , respectively, highlighting the importance of SIP on cloud properties on the global scale.

(4) To investigate the impact of Ice Nucleating Particles (INPs) on ice and mixed-phase clouds at high latitudes, the source attributions of dust aerosols were examined in the Arctic regions. Specifically, the source attribution of dust aerosols in the Arctic and relative importance of high-latitude (Arctic) dust (HLD) versus long-range transported low-latitude dust (LLD) to the Arctic INP population were quantified by using a dust source-tagging method in E3SM (**Shi et al., 2022**). HLD is responsible for 30.7% of the total dust burden in the Arctic (mainly in the planetary boundary layer), whereas LLD from Asia and North Africa contributes 44.2% and 24.2% to the total dust burden, respectively, mainly above 700 hPa.

We compared modeled INP concentrations with INP observations, including those from the M-PACE, ISDAC, and the Ice Nucleating Particles at Oliktok Point (INPOP) ARM campaigns. The modeled INP concentrations show better agreement with both ground and aircraft INP measurements in the Arctic when the model includes HLD INPs. Furthermore, we quantified the cloud radiative effects of HLD as well as LLD from North Africa and East Asia by acting as INPs. It is found that HLD INPs induce a net cooling effect (-0.24 W m^{-2} above 60° N) on the Arctic surface downwelling radiative flux by glaciating and reducing the liquid water in the Arctic mixed-phase clouds. The magnitude of this cooling induced by the two LLD INP sources are relatively small (0.08 W m^{-2} for North African dust and -0.06 W m^{-2} for East Asian dust), which reflects different seasonalities of HLD and LLD. This work (Shi et al., 2022) represents the first modeling study to examine the impacts of HLD on the cloud formation in the Arctic.

In the book chapter (Murray and Liu, 2022), we summarized different approaches that have been used to parameterize the INP spectrum for use in cloud, weather, and climate modeling. We compared the INP concentrations using these parameterizations with observations, highlighting the importance of aerosol-aware parameterizations accounting for aerosol properties (e.g., size, composition, ice active site). We quantified the impacts of INPs on mixed-phase and cirrus clouds based on global model simulations, and discussed the role of INPs and ice processes in shallow mixed-phase, deep convection and anvil cirrus, and in situ cirrus cloud feedbacks.

2. Publications, Conference Presentations, and Synergistic Activities

Over the project period (2020 – 2025), our team published **12** peer-reviewed journal articles and 1 manuscript in review, led by PI Diao and Co-I Liu's team. The * sign indicates students or a postdoc from PI Diao's group.

Please note that some more recent work was partially supported by this ASR grant during the no-cost extension period, and partially by other grants from the PI or Co-I group:

Journal articles led by PI Diao's group (in chronological order):

1. Yang, C.A.*, M. Diao, A. Gettelman, K. Zhang, J. Sun, W. Wu, G. McFarquhar, Ice and Supercooled Liquid Water Distributions over the Southern Ocean based on In Situ Observations and Climate Model Simulations, *Journal of Geophysical Research: Atmosphere*, 126, e2021JD036045. <https://doi.org/10.1029/2021JD036045>, 2021.
2. Yip, J.*, M. Diao, I. Silber, A. Gettelman. Evaluation of the CAM6 climate model using cloud observations at McMurdo Station, Antarctica. *Journal of Geophysical Research: Atmospheres*, 126, e2021JD034653. <https://doi.org/10.1029/2021JD034653>, 2021.
3. Desai, N.*, M. Diao, Y. Shi, X. Liu, and I. Silber. Ship-based Observations and Climate Model Simulation of Cloud Phase over the Southern Ocean, *Journal of Geophysical Research: Atmospheres*, 128, e2023JD038581. <https://doi.org/10.1029/2023JD038581>, 2023.
4. Maciel, F. V.*, M. Diao, and C. A. Yang*. Partition between supercooled liquid droplets and ice crystals in mixed-phase clouds based on airborne in situ observations, *Atmos. Meas. Tech.*, 17, 4843–4861, <https://doi.org/10.5194/amt-17-4843-2024>, 2024.

5. Barone, T., Diao, M., Shi, Y., Zhao, X., Liu, X., & Silber, I. Impacts of synoptic-scale dynamics on clouds and radiation in high southern latitudes. *Journal of Geophysical Research: Atmospheres*, 129, e2023JD040329. <https://doi.org/10.1029/2023JD040329>, 2024.
6. Desai, N.*, M. Diao, Y. Shi, X. Liu. A comparative study of cloud properties between northern and southern high latitudes based on ARM observations and EAMv2 simulations. *Journal of Geophysical Research: Atmospheres*, 130, e2024JD041588. <https://doi.org/10.1029/2024JD041588>, 2025.
7. Yang, C.A.*, M. Diao, Y. Shi, X. Liu. Hemispheric Asymmetry of Phase Partition in Mixed-Phase Clouds Based on Near Global-Scale Airborne Observations, *Geophysical Research Letters*, 2025GL115946, in review.

Journal articles led by Co-I Liu's group (in chronological order):

8. Zhao, X., X. Liu, V. Phillips, and S. Patade (2021), Impacts of secondary ice production on Arctic mixed-phase clouds based on ARM observations and CAM6 Single-Column Model Simulations, *Atmospheric Chemistry and Physics*, 21, 5685–5703, <https://doi.org/10.5194/acp-21-5685-2021>.
9. Zhao, X. and X. Liu (2021), Global importance of secondary ice production, *Geophysical Research Letters*, 48, e2021GL092581. <https://doi.org/10.1029/2021GL092581>.
10. Zhao, X., and X. Liu (2022), Primary and secondary ice production: Interactions and their relative importance, *Atmospheric Chemistry and Physics*, 22, 2585–2600. <https://doi.org/10.5194/acp-22-2585-2022>
11. Shi, Y., X. Liu, M. Wu, Z. Ke, and H. Brown (2022), Relative importance of high latitude local and long-range transported dust to Arctic ice nucleating particles and impacts on Arctic mixed-phase clouds, *Atmospheric Chemistry and Physics*, 22, 2909–2935, <https://doi.org/10.5194/acp-22-2909-2022>.
12. Murray, B. and X. Liu, “Ice-Nucleating Particles and Their Effects on Clouds and Radiation”, In: *Aerosols and Climate* [K. Carslaw (ed.)], Wiley Publisher, 2022. <https://doi.org/10.1016/B978-0-12-819766-0.00014-6>.
13. Zhao, X., X. Liu, S. Burrows, P. J. DeMott, M. Diao, G. M. McFarquhar, S. Patade, V. Phillips, G. C. Roberts, K. J. Sanchez, Y. Shi, and M. Zhang (2023), Important ice processes are missed by the Community Earth System Model in Southern Ocean mixed-phase clouds: Bridging SOCRATES observations to model developments, *Journal of Geophysical Research*, 128, e2022JD037513. <https://doi.org/10.1029/2022JD037513>.

Student theses/dissertations:

1. Yang, C.A. “Ice and Supercooled Liquid Distributions Based on in Situ Observations and Climate Model Simulations”. Master's Theses. 5327. DOI: <https://doi.org/10.31979/etd.cfnq-d2tc>, https://scholarworks.sjsu.edu/etd_theses/5327, August, 2022.
2. Maciel, F.V. “The Influence of Aerosols on Ice and Mixed-Phase Clouds Based on In-Situ Observations and CAM6 Simulations”. Master's Theses. 5318. DOI: <https://doi.org/10.31979/etd.q42j-fywq>, https://scholarworks.sjsu.edu/etd_theses/5318, August, 2022.
3. Shi, Y., “Quantifying dust ice nucleation effects on mixed-phase clouds and contributions from arctic emissions and agricultural sources”, Texas A&M University, Ph.D. dissertation, August 2022.

Conference presentations or seminars given by PI Diao:

1. Diao, M. R. Patnaude, X. Liu, S. Chu, Ice Microphysical Properties Below -40°C based on Seven NSF Flight Campaigns and NCAR CAM6 Model Simulations. NCAR CESM Workshop, June 16, 2020 (virtual).
2. Diao, M. Clouds and Aerosols: The Wild Cards in Climate Change and Air Quality, SJSU College of Science Virtual Seminar, July 31, 2020 (virtual).
3. Diao, M., R. Patnaude, C. Yang, Aerosol Indirect Effects on Ice and Mixed-phase Clouds based on Eight NSF Flight Campaigns and Climate Model Simulations, AGU Fall 2020 oral, Dec 16, 2020 (virtual).
4. Diao, M., C. Yang, A. Gettelman, K. Zhang, J. Sun. Mixed-phase Clouds and Aerosol Indirect Effects over the Southern Ocean based on In-Situ Observations and Climate Model Simulations, AMS Annual Meeting 2021 oral, Jan 13, 2021 (virtual).
5. Diao, M., Advance the Understanding of Clouds and Aerosols by Linking In-Situ Measurements, Satellite Observations and Climate Model Simulations, NASA Ames Earth Science Division Seminar, March 18, 2021 (invited).
6. Diao, M., R. Patnaude, X. Liu, and S. Chu. Global-scale Aircraft Observations and Simulations of Cirrus Clouds and Aerosol Indirect Effects, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-420, <https://doi.org/10.5194/egusphere-egu21-420>, 2021 (virtual).
7. Diao, M., J. Yip, C.A. Yang, A. Gettelman, I. Silber, K. Zhang, J. Sun. Ice and Mixed-Phase Cloud Characteristics over McMurdo, Antarctica and the Southern Ocean, AMS 16th Conference on Polar Meteorology and Oceanography Virtual Meeting, June 3, 2021.
8. Diao, M., J. Yip, C.A. Yang, A. Gettelman, I. Silber, K. Zhang, J. Sun, X. Liu, W. Wu, G. McFarquhar. Ice and Mixed-phase Cloud Characteristics and Aerosol Indirect Effects in High Southern Latitudes. NCAR CESM Workshop, June 6 – 8, 2021.
9. Diao, M., N. Desai, C.A. Yang, J. Yip, X. Liu, I. Silber, A. Gettelman, K. Zhang, J. Sun, W. Wu, G. McFarquhar. Mixed-Phase Cloud Processes and Aerosol Indirect Effects over Southern Ocean and Antarctica, DOE ARM/ASR PI Meeting, June 21 – 24, 2021.
10. Diao, M., R. Patnaude, V. Maciel, D. Ngo, X. Liu and S. Chu. Cirrus Cloud Formation and Evolution Based on Global Aircraft Observations and Simulations. International Commission on Clouds and Precipitation (ICCP) 2021 Conference, August 2, 2021.

11. Diao, M. Advance the Understanding of Clouds and Aerosols by Linking In Situ Measurements, Satellite Observations and Climate Model Simulations. Lawrence Livermore National Laboratory Seminar, September 15, 2021 (invited).
12. Diao, M. Evaluation of Ice and Mixed-Phase Cloud Characteristics in GCMs based on In-situ and Remote Sensing Observations over the Southern Ocean and Antarctica. AGU Fall Annual Meeting 2021. December 17, 2021 (poster).
13. Diao, M., Aviation Effect on Climate Change, NASA Ames – SJSU Aviation & Climate Change Forum Flyer. January 20, 2022 (invited).
14. Diao, M. Ice and Mixed-phase Cloud Microphysical Properties and Aerosols Indirect Effects based on Multi-scale Observations and Climate Model Simulations. NCAR EOL seminar, March 29, 2022 (invited virtual talk).
15. Diao, M. Airborne and Ground-based Observations of Water Vapor, Clouds and Aerosols, and Applications in Climate Research, 2022 Optical Sensors and Sensing Congress, July 11, 2022 (invited talk).
16. Diao, M. Ice and Mixed-Phase Clouds in the High Latitudes based on Multiple ARM Observation Platforms and Climate Simulations, research seminar at DOE Brookhaven National Laboratory, August 24, 2022.
17. Diao, M. Linking multi-scale observations and simulations of mixed-phase clouds based on DOE MARCUS, MICRE and AWARE campaigns, DOE ARM/ASR PI Meeting, October 25, 2022, virtual.
18. Diao, M. Evidence of Secondary Ice Production based on In-situ and Remote Sensing Observations in the High Latitudes, DOE ARM/ASR PI Meeting, October 26, 2022, virtual.
19. Diao, M. Aerosol indirect effects on cirrus cloud formation and evolution, NASA AOS satellite workshop, Nov 17, 2022, virtual.
20. Diao, M. Developing Partnership between San Jose State University and DOE Lawrence Livermore National Laboratory to Enhance Climate Research Equity and Inclusion, DOE RDPP PI meeting, Jan 12, 2023, virtual.
21. Diao, M. Clouds and Aerosols – the Wildcards of Climate Change, SJSU College of Science weekly seminar, February 17, 2023.
22. Diao, M. Hemispheric Comparisons of Ice and Mixed-Phase Cloud Properties based on In-situ Observations and DOE E3SMv1 Model, DOE ASR/ARM PI meeting, breakout session, August 9, 2023 (invited).
23. Diao, M. Challenges, Needs, Opportunities, to Get Your Feet (Back) in the Door, NCAR FARE User Workshop, September 19, 2023, Boulder, CO (invited).
24. Diao, M. Clouds and Aerosols – Two Wildcards in A Changing Climate, DOE PNNL HBCU/MSI seminar series, joint seminar with weekly seminar, October 24, 2023.
25. Diao, M. Cirrus Cloud Microphysical Properties and Aerosol Indirect Effects Using Global-Scale Airborne Observations and Global Climate Model Simulations, AGU Fall Meeting 2023, San Francisco, December 13, 2023 (oral presentation).
26. Diao, M. et al., 9A.5 Aerosol Indirect Effects on Cirrus Clouds based on NASA Flight Campaigns and Global Climate Models, American Meteorological Society (AMS) 104th Annual Meeting, January 31, 2024, Baltimore (oral presentation).
27. Diao, M. Integrating Earth-System Modeling and Multi-Scale Observations to Support Health Studies in California, SJSU WIRC Seminar Series, March 13, 2024 (invited).
28. Diao, M. Clouds and Aerosols – the Two Wildcards of Climate Change, Stanford University Seminar Series, April 5, 2024 (invited).

29. Diao, M. Clouds and Aerosols – the Two Wildcards of Climate Change, Peking University College of Physics Seminar Series, Beijing, China, April 26, 2024 (invited).
30. Diao, M. et al. Cloud Phase and Radiation in High Latitudes based on DOE ARM Field Campaign Observations and DOE E3SM Climate Model, International Radiation Symposium (IRS), Hangzhou, China (oral), June 2024.
31. Diao, M. Cirrus Cloud Microphysical Properties and Aerosol Indirect Effects based on In-Situ Observations and Global Climate Models, International Commission on Clouds and Precipitation (ICCP), Jeju Island, Korea, July 21, 2024 (oral).
32. Diao, M. Panel discussion on applications of the DOE E3SM model, invited speaker, DOE E3SM model 10th year anniversary, December 8, 2024 (invited oral).
33. Diao, M. et al. Examining Partition between Ice Crystals and Supercooled Liquid Water based on Multi-Scale Observations and Climate Model Simulations, AGU Fall Meeting 2024, December 10, 2024 (poster).
34. Diao, M. Serving as a panelist on the NAS BASC board meeting, Extreme Weather and Lessons for More Resilient Communities: Board on Atmospheric Sciences and Climate 2025 Spring Meeting, May 6, 2025 (invited)
35. Diao, M. et al. Advancing the Understanding of Clouds and Aerosols Using Multiscale Observations and Simulations, Naval Research Laboratory, research seminar on May 15, 2025 (invited).

Conference presentations given by Co-I Liu's team:

1. Liu, X., Y. Shi, Impacts of dust on the Arctic mixed-phase clouds through heterogeneous ice nucleation process: high latitude dust emission vs. remote deserts, AGU fall meeting 2020 oral (Virtual), December 7, 2020.
2. Zhao, X., X. Liu, V. Phillips, S. Patade, Global Importance of Secondary Ice Production: Impacts on Cloud Properties and Radiative Forcing, AGU fall meeting 2020 (Virtual), December 7, 2020.
3. Zhang, M., X. Liu, Z. Wang, D. Zhang, S. Xie, Hemispheric differences in macrophysical and microphysical properties of mixed-phase clouds from observations and E3SM simulations, AGU fall meeting 2020 (Virtual), December 7, 2020.
4. Liu, X., X. Zhao, Y. Shi, Vaughan T. J. Phillips, Sachin Patade, Minghui Diao, Susannah Burrows, Impacts of ice production processes on high-latitude mixed-phase clouds, DOE ARM/ASR PI Meeting, June 21 – 24, 2021.
5. Shi, Y., and X. Liu, Relative Importance of High-Latitude Local and Long-Range Transported Dust to Arctic INPs and Impacts on Mixed-Phase Clouds, AMS Annual Meeting 2021 oral, January 13, 2021 (virtual).
6. Zhao X., X. Liu, V. Phillips, S. Patade, G. McFarquhar, M. Diao, C. Yang and N. Desai, Importance of Secondary Ice Production to Ice Formation and Phase of High-Latitude Mixed-Phase Clouds during SOCRATES and MARCUS", American Geophysical Union (AGU) 2021 fall meeting, New Orleans, LA, 13-17 December 2021.
7. Shi, Y., Liu, X., Hou, Y., Alrimaly, S., Wilbourn, E., Mazzola, M., Traversi, R., and Hiranuma, N.: Interannual and interseasonal variabilities and sources of ice nucleating particles in the Arctic: Insights from model and long-term measurements simulations from Ny-Ålesund. AGU Fall Meeting, New Orleans, LA, oral, December 13-17, 2021.

8. Shi, Y., Liu, X., Hou, Y., Alrimaly, S., Wilbourn, E., Mazzola, M., Traversi, R., and Hiranuma, N.: Interannual and interseasonal variabilities and sources of ice nucleating particles in the Arctic: Insights from long-term measurements and model simulations from Ny-Ålesund. 102nd AMS Annual meeting, oral, January 10-15, 2022 (virtual).
9. Liu, X., X. Zhao, J. Zhu, Y. Qin, M. Zelinka, S. Klein, V. Phillips, S. Patade, Secondary ice production in CESM2: Impacts on high latitude clouds, aerosol indirect forcing, and climate sensitivity, NCAR CESM Atmosphere / Whole Atmosphere / Chemistry-Climate Winter Working Group Meeting, 7-10 February 2022 (virtual).
10. Zhao, X., X. Liu, S. Burrows, P. Demott, M. Diao, G. McFarquhar, S. Patade, V. Phillips, Y. Shi, M. Zhang, Important ice processes are missing by the climate model in Southern Ocean mixed-phase cloud: bridging from SOCRATES observation to model development, NCAR CESM Atmosphere / Whole Atmosphere / Chemistry-Climate Winter Working Group Meeting, 7-10 February 2022 (virtual).

Synergistic activities:

- PI Diao served on the DOE ARM Cloud and Precipitation Measurements and Science Group (CPMSG) committee between 2020 – 2024. She is also a board member of the National Academy of Sciences (NAS) Board on Atmospheric Science and Climate (BASC) and participates in regular board meetings since 2023.
- PI Diao and Co-I Liu co-chaired several sessions in AGU Fall Meetings between 2020 and 2024, including “Microphysical and Macrophysical Properties and Processes of Ice and Mixed-Phase Clouds: Linking in Situ, Remote Sensing Observations and Multiscale Models” in 2020 – 2023, and “Atmospheric Ice Processes” in 2024, with both oral and poster sessions.