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The Second Arm Training and Science Application Event: Training the Next Generation of Atmospheric Scientists

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Training the Next Generation of Atmospheric Scientists

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The Atmospheric Radiation Measurement (ARM) user facility (Turner and Ellingson 2016) collects valuable observations of atmospheric variables affecting the Earth's radiation budget. These include properties of aerosol, cloud, precipitation, dynamic, and thermodynamic fields. The ARM user facility also supports routine high-resolution modeling efforts at its Southern Great Plains (SGP) site, and over the years it has had significant impacts on cloud-resolving and Earth system model development (Krueger et al. 2016; Randall et al. 2016). In an effort to promote use of the ARM data by the next generation of atmospheric scientists, the second ARM Summer Training and Science Applications Event on observations and modeling of clouds and precipitation took place from 14 to 21 July 2018. The event was sponsored by the ARM User Facility and was catered toward graduate students and early career scientists interested in observations and modeling of aerosol, cloud, and precipitation processes. Theoretical and practical instructions on the application of ground- and aircraft-based observations from a wide array of active and passive sensors, and finescale-resolution model simulations were provided during the training. This informed the participants about innovative methods for using the ARM data and numerical models to address complex scientific questions. The

2018 ARM SUMMER TRAINING AND SCIENCE APPLICATIONS EVENT

What: Twenty-four graduate students and early career scientists from all over the world gathered to learn about ARM data and the latest observation science.
When: 14–21 July 2018
Where: Norman, Oklahoma

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event was locally organized by the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) and was held at the National Weather Center in Norman, Oklahoma. The training was attended by 12 instructors and 24 participants.

The training event was a follow-on to the first training event held in 2015, and was similar in spirit to the summer and winter schools organized under the umbrella of the European Marie Curie Initial Training Network for Atmospheric Remote Sensing (ITARS; Banks et al. 2016), and the Arctic Amplification: Climate Relevant Atmospheric and Surface Processes, and Feedback Mechanisms [(AC)^3; Wendisch et al. 2017] projects. In mid-February of 2018, the call for applications was announced encouraging graduate students and early career scientists to submit an application by the end of March 2018. The call for applications explicitly mentioned six working groups and the instructors associated with each of them, with an intent that the applicant would express interest in being a member of one of the groups. The application package was expected to have a one-page motivation letter, one recommendation letter, and a résumé. Fifty-two graduate students and 9 postdoctoral scholars from around the world responded to the call for applications, with 7 postdoctoral scholars and 17 graduate students (total of 24) out of the 61 applicants chosen to attend the event. Based on the participant's scientific interest expressed in the motivation letter, each was assigned to one of the six groups (Table 1).

The training event was designed to be hands on. Daily activities—except on the first, fourth, and last days—included two keynote lectures from the instructors in the morning, followed by 5 h of group research activity. Presentations were made on the first day to introduce the participants to the ARM user facility, available data, data quality, and data processing software (e.g., Helmus and Collis 2016). This was followed by short introductions by the instructors to the group projects and an icebreaker gathering. The keynote lectures from the instructors included about an hour of presentation on the instructor's topic of research and were followed by an exercise or short quiz intended to initiate discussion. On the fourth day of the event, the instructors and the participants visited the ARM SGP site to see the instruments and to gain knowledge about practical and logistical challenges in operating a scientific observing facility. The event concluded midday on the last day with each group making a 20-min presentation showcasing results from its group work. After the group presentations, the instructors met to decide on

Table 1. Group name, project title, and project scope during the training event. Each group consisted of two instructors and four participants.

Group No.	Group name	Project title	Project scope
1	Precipitation Microphysics	Multiparameter radar observations for understanding precipitation microphysics and for model evaluation	To interpret radar Doppler spectra and polarimetric data for an event and to evaluate cloud-resolving model simulations using a radar forward simulator
2	Ice/Snow Microphysics	An investigation of Arctic ice cloud processes	To investigate how aggregation and riming affect microphysical properties of ice and mixed-phase clouds
3	High-Latitude Cloud Systems	Radiation and model evaluation of the high latitudes	To understand specifics of the cloud influence on atmospheric radiative budget at high latitudes as compared to midlatitudes, and to study challenges of cloud modeling at high latitudes
4	Shallow Cloud Modeling	Evaluation and analysis of shallow cloud simulations over Oklahoma	To investigate the sensitivity of simulations to boundary conditions and to compare LWP variability with observations
5	Cloud Fraction and Liquid Water Content	Detection and characterization of the subsiding shell around cumulus clouds	To investigate whether ground-based remote sensing allows characterization of shallow cumulus mass flux
6	Boundary Layer Studies	Boundary layer structure during different cloud conditions at the ARM ENA site	To investigate whether marine boundary layers associated with closed and open cellular stratocumuli exhibit a diurnal cycle

the winning group based on presentation style, depth of scientific understanding, cohesiveness of the group work, and other factors. Group 5 was declared the winner and was awarded with a small prize funded by the instructors.

The group research activity was specifically designed to strongly leverage data collected at the ARM sites in conjunction with output from numerical models and satellite-borne instruments. Each group had two instructors and four participants. Described in brief below are the six group projects and their outcomes as reported during the presentations.

1) Precipitation Microphysics: This group project was designed to familiarize the participants with analysis of radar Doppler spectra and polarimetric variables, and to showcase their usefulness in evaluating output from cloud-resolving models through a radar simulator. The participants first analyzed and interpreted i) polarimetric data from the C-Band Scanning ARM Precipitation Radar (C-SAPR), ii) polarimetric data from a Weather Surveillance Radar-1988 Doppler (WSR-88D) S-band radar, and iii) the Doppler spectra and their moments from a 915-MHz wind profiler collected during a mesoscale convective system (MCS) case observed at the SGP site. Next, the group ran the Cloud-Resolving Model Radar Simulator (CR-SIM; Tatarevic et al. 2018) to emulate the radar observables for the MCS case using the Weather Research and Forecasting (WRF) Model output. The CR-SIM simulations were performed using either the participant's computer environments or those at the Ohio Supercomputer Center. The participants combined the radar observational and cloud model data to understand precipitation microphysics and to evaluate the model output.
2) Ice/Snow Microphysics: This group analyzed in situ aircraft observations of ice- and liquid-phase cloud microphysical properties obtained in boundary layer clouds in the vicinity of Utqiaġvik, Alaska, during the 2008 Indirect and Semi-Direct Aerosol Campaign (ISDAC). The goal was to investigate the importance of riming and aggregation processes in determining the cloud microphysical properties. The group focused on statistical analysis of all ice/mixed-phase cloud cases where the ambient temperature was greater than −20°C. To gain insights into snow growth processes, one case study dominated by ice clouds and another by mixed-phase clouds was further analyzed. Looking at mean particle size distributions, mean densities, and mean volume-equivalent diameters, the group determined that i) ice-phase clouds had larger particles relative to mixed-phase clouds; ii) mixed-phase clouds had larger densities and masses indicative of riming; and iii) although aggregation occurred at warmer temperatures in ice-phase clouds, its signatures were seen in both ice- and mixed-phase clouds. They concluded that i) while simple to apply, classifying the clouds as mixed-phase or ice solely based on the presence or absence of supercooled liquid water droplets might yield misleading results; ii) a more comprehensive cloud classification technique that uses data from remote sensing measurements such as microwave radiometer liquid water path and from other in situ probes would be advantageous; and iii) it is difficult to draw broad conclusions from the case studies because of limited sampling.
3) High-Latitude Cloud Systems: The students investigated the specifics of the solar and terrestrial radiation budget at the high latitudes. In particular, the role of clouds was studied by carrying out sensitivity studies using a radiative transfer model [Library for Radiative Transfer (libRadtran); Emde et al. 2016]. The simulations aimed at understanding how the surface radiative budget in high and midlatitudes depends on cloud properties. Radiation data from the ARM SGP and the North Slope of Alaska (NSA) sites were analyzed for selected dates in 2015 that highlighted the importance of clouds for the radiative budget. Further, 10-day forecasts of the WRF Model were compared to observations at the NSA site to investigate the performance of numerical weather models at high latitudes with respect to pressure and atmospheric stability. To evaluate the cloud properties simulated by the model, the Passive and Active Radiative Transfer (PAMTRA) model (Maahn et al. 2015) was used for comparison with cloud radar observations. It was found that the model was successfully able to forecast the trends in these properties for the winter case.
4) Shallow Cloud Modeling: The group members became acquainted with how high-resolution large-eddy simulation (LES) modeling can complement observations. The group's project consisted of two branches: i) to explore the sensitivity of cumulus fields to boundary conditions, such as evaporative fraction and relative humidity; and ii) to compare the variability of liquid water path (LWP) time series extracted from simulations with available observations in

a broken cloud field. The participants ran the LES model themselves, using computing time offered by the Ohio Supercomputer Center (OSC 2016). Using these computational facilities, the group ran several simulations each day based on the LES ARM Symbiotic Simulation and Observation (LASSO) simulations of cumulus clouds over the SGP site (Gustafson et al. 2017). It was found that simulated domain-mean LWP was sensitive to boundary conditions but poorly constrained by the available zenith measurement.

5) Cloud Fraction and Liquid Water Content: This group took up the challenge to prove a theory originating from LES modeling of shallow cumulus clouds (Jonker et al. 2008), suggesting that the downward mass transport is dominated by processes just outside the cloud rather than the large-scale environment between individual clouds. While airborne in situ measurements could already reveal this subsiding shell, the group used ground-based remote sensing observations from the SGP site to detect and characterize the subsiding shell around cumulus clouds. They identified several days with cumulus clouds using Doppler lidar backscatter profile data and developed an objective technique to analyze vertical wind speed below cloud and relative to the cloud edge from time–height cross sections. Furthermore, they performed a statistical analysis revealing that the front edge of cumulus clouds had stronger updrafts and that the subsiding shell is stronger on the back edge of clouds.
6) Boundary Layer Studies: The overall aim of this group's project was to investigate whether marine boundary layer stratocumulus clouds associated with closed and open cellular mesoscale organization exhibit a diurnal cycle. The group first identified three cases each of open and closed cellular stratocumuli over the ARM eastern North Atlantic (ENA) site using satellite and ARM data. Then they analyzed the data collected by radiosondes, laser ceilometer, microwave radiometer, radar wind profiler, Doppler lidar, Ka-band ARM zenith radar (KAZR), and output from the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis model during the cases. They investigated the hourly statistics of cloud boundaries, cloud fraction, rain rates, liquid water path, boundary layer inversion, and subcloud turbulence for the cases. Their results collectively suggested significant differences in the cloud and boundary layer properties between the open and closed cellular organizations, but also the absence of a distinct diurnal cycle. They called for better characterization of the uncertainty in the retrieved parameters and analysis of more cases to build robust statistics.

The event brought together scientists (instructors) from the United States and Europe with expertise in instrumentation, retrieval techniques, and modeling with a range of scientific focus. This not only enabled the participants to interact with experts with different scientific cultures and focuses but also fostered collaborations between U.S. and European counterparts (Haeffelin et al. 2016). With 19 (out of 61) applicants, 4 (out of 24) selected participants, and 4 (out of 12) instructors from institutions outside of the United States, the event highlighted interest in the ARM data and the training event from the international scientific community.

Over the last three years (2015–17) 87 undergraduate and 120 graduate students have visited the ARM sites in some capacity. During the same period, 39 students have presented posters as a first author at the joint ARM and Atmospheric System Research Principle Investigators meeting. This suggests that the ARM user facility is being used in training the next generation of scientists at both graduate and undergraduate levels. However, currently very few U.S. universities have observing facilities with instruments for observing aerosol and cloud properties, with none of them having instrumentation as comprehensive as at the ARM sites. Hence, with continuous operation of more than 100 instruments, the ARM sites make an ideal location for students and early career scientists to gain hands-on experience in atmospheric instrumentation and to understand its scientific value through such a training event.

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