Final Report

Grant No. DE-FG02-05ER64058
"Site Scientist for the North Slope of Alaska Site"

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Executive Summary

Under this grant our team contributed scientific support to the Department of Energy Atmospheric Radiation Program's (DOE-ARM) Infrastructure team to maintain high quality research data at the DOE-ARM North Slope of Alaska with special emphasis on the radars. Under our guidance two major field campaigns focusing on mixed-phase Arctic clouds were conducted that greatly increased the community's understanding of the many processes working together to control the evolution of single-layer cloud mixed-phase clouds. A series of modeling and observational studies revealed that the longevity of the radiatively important liquid phase is strongly dependent on how the ice phase develops in mixed-phase clouds. A new ice microphysics parameterization was developed to capture better the natural evolution of ice particle growth in evolving environments. An ice particle scattering database was developed for all ARM radar frequencies. This database was used in a radar simulator (Doppler spectrum and polarimetric variables) to aid in the interpretation of the advanced ARM radars. At the conclusion of this project our team was poised to develop a complete radar simulator consistent with the new microphysical parameterization, taking advantage of parameterization's advanced characterization of the ice shape and ice density.

1. Overview

This report covers the period 2005 through 2015. During this period the expectations from DOE-ARM/ASR evolved from primarily providing science support to site management and promoting the NSA site to the ARM (later ASR) science team to a fully science focus. This shift in programmatic expectations resulted in an initial focus on field experiments to draw ARM Science Team members to the NSA, while at the same time working with the ARM Infrastructure to improve data quality at the North Slope. The *Mixed-Phase Arctic Cloud Experiment* and the *Indirect- and Semi-Direct Aerosol Campaign* played large roles in establishing a strong group of ARM/ASR researchers on critical Arctic mixed-phase cloud processes. These data sets are still heavily used for Arctic research throughout the international community. After 2009 our focus shifted to our research foci of radar observations and numerical modeling of mixed-phase processes. Our team had been instrumental in development of new processing techniques for profiling radar Doppler spectra and polarimetric radar analysis, and has implemented a new microphysical parameterization for ice processes in the Weather Forecasting and Research model. At the same time we worked on closing the link between modeling and observation by developing a ice hydrometeor electromagnetic scattering data base (for all radar frequencies used by ARM) that allow us to develop a radar simulator that is consistent with the assumptions underpinning the microphysical parameterization.

2. Overview of Site Scientist Team Activities

2.1 Site Scientist Team Contributions to Site Operations, Field Campaigns

Field Programs:

The Indirect- and Semi-Direct Aerosol Campaign (ISDAC) was conducted over the North Slope in April 2008 in concert with the NASA Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) and the NOAA Aerosol, Radiation and Cloud Processes affecting the Arctic (ARCPAS) experiments. These three experiments produced a comprehensive dataset of microphysical and radiative properties of aerosols and clouds in the arctic boundary layer in the vicinity of Barrow. The primary aim of ISDAC was to examine indirect effects of aerosols on clouds that contain both liquid and ice water. ISDAC built on and was the spring contrast to the fall M-PACE experiment.

Two more field projects were proposed and approved. The Routine In Situ Cloud and Aerosol Measurements (RISCAM) campaign was canceled because of a shortage of program funds, and the follow up Arctic Lower Troposphere Observed Structure (ALTOS) experiment was terminated early when the principle observing platform, a tethered-balloon system, was lost when the tethers broke. These two experiments illustrate the cost and difficulty of conducting cloud experiments in extreme arctic conditions: aircraft campaigns are expensive because of safety requirements imposed by frequent in-cloud icing conditions, while other alternatives (e.g. tethered-balloon systems) come with high risk and a steep learning curve.

We also conducted the NSA Snow IOP (in winter 2011) in Barrow. This IOP was initiated from our team and was in support of the larger science objective of interpreting the scanning precipitation radar measurements. The specific Snow IOP objectives were to determine if the ARM 2-D Video Disdrometers could function in the cold Arctic temperatures and capture ice-precipitation particle properties in sufficient detail to allow accurate modeling of their scattering properties. The answer to both questions was no. Low temperatures resulted in peeling mirror films, which reduced the usable sample volume of the instrument, and we learned that the standard signal processing of the instrument failed to correctly identify the coincident views of the same ice crystals. (The processor was developed with faster falling raindrops in mind.) In response to these results we proposed the acquisition of a Multi-Angle Snow Camera designed specifically to capture high speed, high resolution images of ice particles from three different view angles as they fall through the sample volume. This instrument went through a successful deployment in Barrow in April 2015. The instrument provides direct measurements of particle shape (and potentially mass from tomographic particle reconstructions) and fall speed, both critical measurements needed to constrain cloud and forward scattering models.

Support for the ARM program NSA initiatives:

During the last grant period the decision was made to deploy an ARM Mobile Facility at Oliktok Point to exploit the restricted air space allocation developed for the Mixed-Phase Arctic Cloud Experiment. Because of our experience working on the North Slope and also at Oliktok Point, our team worked closely with the Sandia NSA Site Operations Team led by Mark Ivey to develop plans for the initial deployment of instruments and future science objectives. Hans Verlinde and Scott Richardson made several trips to Oliktok Point to help site operations make decisions on the placement of instruments, and Scott Richardson was on site in Oliktok Point during the implementation phase of the AMF in 2013. At the same time Hans Verlinde worked with Mark Ivey, Bob Ellingson and Rick Petty to organize a planning and operational workshop on “Polar Atmospheric Measurements Related to the DOE ARM Program Using Small Unmanned Aircraft Systems and Tethered Balloons” in Washington, DC in July 2013, the recommendations of which were published as a DOE ARM program Technical report. Following that workshop, Hans Verlinde again work with Mark Ivey and Bob Ellingson to organize another workshop to establish priorities for the North Slope of Alaska in Washington, DC in September 2014, with recommendations reported in a separate DOE-ARM Technical report.

Support for the ARM NSA radars:

Much of the focus of the site scientist team has been to bring the ARM NSA radars up to research quality. To that effect we worked closely with the Radar Science group (Eugene Clothiaux being our representative) to improve the data quality of the radars.

MMCR:

We collaborated with the BNL radar group to show the shortcomings of the post 2007 MMCR processor for Doppler spectra. This work eventually led to the program developing better standards for spectra processing and the procurement of the KAZR 1 radars throughout the ARM program.

We collaborated with Alain Protat on quantifying the error in the Barrow MMCR reflectivities using CloudSat reflectivities as a measure of truth. This exercise was part of a broader study that compared the calibration of cloud radars located all over the world. This analysis revealed that the NSA radar was measuring 9.8 dB high. The cause for this offset was never established.

KAZR:

The MMCR replacement came with its own set of initial problems. We documented an 8 dBZ offset in calibration between the two modes used in the Barrow KAZR. The KAZR data now reports high quality data.

SACR:

We documented that the W-SACR has very poor sensitivity, resulting in even strong cloud returns being lost in the noise at distances beyond a few kilometers. This was reported to the Radar Science group.

We documented that there is an 8 dB calibration offset between the Ka-SACR and the W-SACR, with each radar calibration corresponding to a different KAZR mode calibration. This was reported to the Radar Science group. Where SACR data exist all is salvageable as the correction follows the KAZR correction.

Unfortunately the Barrow SACR has proven to be highly unreliable, sufficiently so that no scientific papers were possible.

X-SAPR:

Initial analysis revealed that the data quality from the X-SAPR was below research standards. We initiated an IOP request to collected raw radar data to explore processing strategies to improve the data quality of the X-SAPR and also design optimal scanning strategies for the X-

SAPR and SACR radars. The IOP investigator group included several of the new ASP investigators with strong precipitation radar experience (Chandrasekar, Ryzhkov, Galletti) and people from various DOE laboratories, bringing together the precipitation and cloud radar expertise groups in ASR on a combined project. Our group published several papers from this IOP.

Science Support for the Oliktok Point AMF3:

The site scientist team has worked closely with Mark Ivey on developing plans for the AMF3. We have established week calls between Mark Ivey, Hans Verlinde and Scott Richardson to discuss various issues, including tether balloon system operations. Verlinde has made two trips to Oliktok Point with Mark Ivey in 2012, and participated in a DOE Headquarters – FAA – Sandia workshop in Albuquerque to discuss Unmanned Aerial System operations at Oliktok Point. We (Verlinde and Clothiaux) participated in the Radar Science group discussions about the needs for the Oliktok Point scanning systems, leading to the decision to not request an X-SAPR for Oliktok Point but rather request a fully polarimetric system with greater potential for informing on the spatial distribution of the microphysical characteristics of clouds.

2.2 Site Scientist Team Science Contributions

Throughout all our activities we placed strong emphasis on collaborative efforts with other ARM/ASR research teams even as we tried to knit our efforts together to develop a comprehensive observational/modeling strategy to study mixed-phase clouds. We are collaborating with modeling groups at NASA GISS (Fridlind and Ackerman), NCAR (Morrison) and NOAA (Feingold). Our retrieval work has reached the level of maturity that allows us to place decoupled microphysical and dynamical constraints on Cloud Resolving Models (CRMs). Such constraints are necessary as we seek to understand the critical processes that determine the characteristics of Arctic low-level mixed-phase clouds.

Our research activities over the years focused on several specific topics under the broad theme of Arctic cloud processes (lists of refereed publications following topic):

1. Mixed-phase cloud processes: Verlinde et al. (2007), Prenni et al. (2007), Klein et al. (2008), Morrison et al. (2008), Lebo et al. (2008), Avramov and Harrington (2010), McFarquhar et al. (2011), Avramov et al. (2011), Ervens et al. (2011), Morrison et al. (2011, 2012), Ovchinnikov et al. (2014)
2. Retrieval of microphysical and dynamical characteristics of mixed-phase clouds: Shupe et al. (2008), Oue et al. (2015a,b; 2016), Rambukkange et al. (2011), Verlinde et al. 2013), Yu et al. (2014), Wang et al. (2016)
3. Parameterization of ice processes in cloud-resolving models: Harrington et al. (2013a,b), Sulia et al. 2013), Jensen and Harrington (2015)

4. Linking observational/modeling activities - scattering calculation of ice hydrometeor at millimeter wavelengths in support of the new scanning radars: Botta et al. (2010), Botta et al. (2011), Botta wet al. (2013), Lu et al. (2013)
5. Larger-scale connections: Johnson et al. (2008, 2010), Yannuzzi et al. (2008)
6. Support for operations: Hanlon et al. (2013), Small et al. (2011), Peppler et al. (2012), Protat et al. (2011), Ivey et al. (2013), Verlinde et al. (2015)

Over the course of the project we contributed to the development of a good understanding of the processes working together to sustain single-layer mixed-phased Arctic cloud processes (summarized in Morrison et al. 2012), and we led the community in the description of processes operating in multilayered mixed-phase clouds. We showed that the evolution of the cloud (longevity) depends on the specifics of the *a priori* prescribed characteristics of the ice microphysics, particularly as these impact in-cloud times of ice particles. No existing microphysical parameterization could simultaneously evolve the mass, aspect ratio, and particle fall-speed consistently as these particles advect/precipitate inside the cloud. We developed an alternative ice microphysical parameterization that has the additional advantage that its ice hydrometeor characteristics are compatible with radar reflectivity simulators, thus removing a large ambiguity in radar/model evaluations. We showed that the radar reflectivity simulator adapted by the modeling community (Quickbeam) is prone to large uncertainty because the modelers are required to specify parameters is input that is not available (or pre-specified) in their models (variable size, shape and bulk density). To aid the development of an appropriate radar reflectivity simulator we created a scattering database and a methodology to use the output of our newly developed ice microphysics parameterization to produce radar reflectivity estimates consistent with the model-produced ice hydrometeors. The database will be submitted to the ARM archive by March 2016 and will be freely available to the community

We have developed a tool to separately retrieve the liquid/ice phase contributions to the total reflectivity in Doppler velocity spectra, which allowed us to study multi-layered mixed-phase cloud processes in detail using the new DOE-ARM polarimetric radars.

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