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Retrieval of Cloud Properties and Direct Testing of Cloud and Radiation Parameterizations Using ARM Observations

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1. Introduction

In these past (and last) three years of our funding under DOE Grant DE-FG02-90ER61071 we proposed to focus our research on the following topics:

a) removal of artifacts in the Doppler spectra from the ARM cloud radars;

b) development of the second generation Active Remote Sensing of Cloud Layers (ARSCL) cloud data products;

c) evaluation of ARM cloud property retrievals within the framework of the EarthCARE simulator.

As before, we would continue to pursue research on areas related to radiative transfer, atmospheric heating rates and related dynamics (topics of interest to the ARM science community at this time) and to contribute on an ad-hoc basis to the science of other ARM-supported principal investigators.

2. Results

Each of the first three topics developed idiosyncrasies during the course of the past three years that precluded us from reaching finality in our research pertaining to them. That said, we nonetheless made significant progress in advancing our knowledge on them. We next describe the problems that we encountered and what we accomplished, providing a brief characterization of the work that yet needs to be done.

a. Removal of Artifacts in the Doppler spectra

Detecting and characterizing cloud drops in the presence of precipitating particles are important science objectives in cloud and climate research. Doppler spectra from the ARM cloud radars remain as one path for successfully accomplishing this goal. The problem with the original ARM cloud radars was that the strong returns from precipitating particles often created spurious signals in the Doppler spectra that masked the cloud signals. There was nothing intrinsically wrong with the original ARM cloud radars; rather, separation of cloud from precipitation returns in Doppler spectra is an intrinsically demanding problem, placing the most stringent demands on current radar technology. During our three years of funding, various ARM cloud radars were upgraded with C-40, PIRAQ and DIGITAL processors. In every case the spurious returns from precipitation remained in the Doppler spectra, attesting to the difficulty of separating cloud and precipitation returns.

To demonstrate the value of Doppler spectra from the ARM cloud radars for cloud and climate research, Mahlon Rambukkange (a graduate student supported by ARM funding) analyzed in exquisite detail a 30-minute period of Doppler spectra from the ARM NSA cloud radar during an interesting period of the Mixed Phase Arctic Clouds Experiment (MPACE). The analysis was time consuming because the final methodology for separating cloud and precipitation returns included manual intervention. The effort was worth it, as they were able to detect and characterize two liquid water cloud layers embedded in ice precipitation. Their paper (Rambukkange et al., 2010) illustrates clearly and simply the value of Doppler spectra from the ARM cloud radars for cloud and climate research.

To separate cloud and precipitation returns with high accuracy the ARM program must develop radar hardware and processors that do not produce spurious returns from precipitating particles. The current radars being developed with American Recovery and Reinvestment Act (ARRA) funding and slated for deployment towards the end of 2010 and into 2011 provide the program's best next opportunity to solve this problem. We will see.

b. Development of the Second Generation ARSCL Cloud Data Products

Working with Pavlos Kollias and other ARM investigators we developed a perspective on the many ways that the ARM cloud radars could contribute to cloud and climate research (Kollias et al., 2007b). Implicit to this perspective was characterization of processing problems related to the original ARM cloud radars (Kollias et al., 2005) and development of processing strategies that fixed them (Kollias et al., 2007a; Luke et al., 2008). As Kollias et al. (2007a) indicate, we made significant progress in developing ideas for the second generation ARSCL cloud data products. Implementation of these ideas was much more problematic as the program and many of its scientists, including us, became entwined in discussions and activities devoted on how best to evolve ARM cloud remote sensing hardware.

As we learned more about problems in many of the original ARM cloud remote sensing instruments, we developed new ideas for improved algorithms to process the data from these instruments and we came up with instrument specifications that future instruments would need to have to remove problems in the data from the original instrumentation. The work by Turner et al. (2007) on ARM microwave radiometry was quite akin to the work by Kollias et al. (2005) on the ARM cloud radars. Turner et al. (2007) characterized the limits on the accuracies of cloud liquid water path retrievals using existing ARM microwave radiometers. Other similar studies, coupled with a workshop that we helped to organize pertaining to the future of ARM microwave radiometry, assisted the ARM program in developing an evolutionary path for its microwave radiometers. The ARM program started the acquisition of its future radiometers in the 2008 and 2009 time period. This process was substantially accelerated by ARM's acquisition of significant ARRA funding for the enhancement of its core infrastructure.

When the ARM program received its ARRA funding, it was well-positioned to articulate its future instrument needs. For example, the work by Kollias et al. (2005), Kollias et al. (2007a) and Kollias et al. (2007b) contributed to a body of research that made clear problems in the existing ARM cloud radar data and the nature of future hardware that would be necessary to ameliorate these problems. The work by Turner et al. (2007) made similar contributions to ARM microwave radiometry research. The ARM program is now spending significant effort on the acquisition of its future cloud radars and microwave radiometers that it must have to advance it scientific goals. Our research contributed to this effort and we, like others, are waiting for the ARM program to deploy its next generation of cloud remote sensing instruments.

c. Evaluation of ARM Cloud Property Retrievals within the Framework of the EarthCARE simulator

Evaluation of ARM cloud property retrievals within a self-consistent, systematic framework, like the EarthCARE simulator (Voors et al., 2007; Donovan et al., 2008), will one day be quite important within the ARM program. ARM program scientists are moving in this direction and we anticipate that in the near future this will become a reality. Perhaps with the deployment of future ARM cloud remote sensing instruments problematic data will be sufficiently reduced so as to enable ready implementation of the best cloud retrieval algorithms and rigorous evaluation of their results. Given the many problematic issues in the existing ARM cloud radar and microwave radiometer data and their downstream products and our involvement in their resolution, we ended up in a position of not being able to spend significant effort on the evaluation of ARM cloud property retrievals within the framework of the EarthCARE simulator. This is not to say that the EarthCARE simulator evolved in a manner inconsistent with ARM goals. In fact, it did.

David Donovan, the lead scientist in the development of the EarthCARE simulator, has continued to evolve the EarthCARE simulator in a manner consistent with ARM goals. The key scientific components of the EarthCARE simulator remain in the public domain and bug fixes within these components have continued. Most importantly, David Donovan and his colleagues have now implemented simulators for ground-based radars and lidars into the EarthCARE simulator framework (Placidi et al., 2009). Such implementation of simulators for ground-based instruments into the EarthCARE framework was a key proposal goal and it has now been accomplished. As a result, the EarthCARE simulator is more relevant to ARM program goals than it was several years ago. It remains as a viable option for the implementation of self-consistent, systematic evaluations of ARM program cloud property retrievals.

3. Brief Summary of Related Research

In addition to our research findings elucidated above we continued to contribute to other scientific investigations relevant to the ARM program.

Implications of the neglect of three-dimensional radiative transfer on atmospheric irradiances and heating rates have long been of interest to the scientific community. Hinkelman et al. (2007) investigate this issue within anisotropic cumulus cloud fields, demonstrating that one-dimensional, vertical radiative transfer is not as accurate as one-dimensional, tilted radiative transfer. Studies related to three-dimensional radiative transfer and the nature of errors in cloud microphysics that might expect to negatively impact both one- and three-dimensional radiative transfer were pursued by Petters (2009). The work of Petters (2009) is now being prepared for peer-reviewed publications.

The work by Naud et al. (2008) uses ARM cloud radar data to investigate the relationship between atmospheric dynamics, atmospheric thermodynamics and cloud overlap. This type of investigation would benefit greatly by improved separation of cloud and precipitation particles using Doppler spectra from the ARM cloud radars.

Ivanova et al. (2006) and Ivanova et al. (2007) investigate detailed cloud structures and methods for characterizing them. The ultimate aim of these types of studies is linking statistical properties of clouds to prevailing dynamics and thermodynamics with subsequent characterization of their radiative properties.

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