Small Particles in Cirrus (SPartICus) and Storm Peak Lab Validation Experiment (StormVEx) Science
Final Technical Report

ID: DESC0007062
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Title: SpartICus and StormVEx Science

SC Division: SC-23.1
Program Manager: Ashley D. Williamson 301-903-3120
Research Areas: ASR
Project Period: 9/15/2011 - 09/14/2014

Abstract: The Small Particles in Cirrus (SPartICus) campaign took place from January through June, 2011 and the Storm Peak Lab Cloud Property Validation Experiment (StormVEx) took place from November, 2011 through April, 2012. The PI of this project, Dr. Gerald Mace, had the privilege to be the lead on both of these campaigns. The essence of the project that we report on here was to conduct preliminary work that was necessary to bring the field data sets to a point where they could be used for their intended science purposes. In the following paragraphs, I describe what we have accomplished during the period of funding.

The SPartICus campaign was supported by the ARM Aerial Facility and consisted of collecting a long-term in situ data set in cirrus over and in the vicinity of the ARM SGP site by the Stratton Park Engineering (SPEC) Lear Jet. In addition, the NASA-sponsored Middle Latitude Airborne Cirrus Experiment (MACPEX) was conducted by the NASA WB-57 aircraft operating out of Ellington field during Spring of 2011. MACPEX was conceived as an extension of SPartICus and several flights were conducted over the SGP site during April 2011. During the 6-month period of the SPartICus campaign, approximately 200 hours of research data were collected using a suite of state-of-the-art in situ probes. Our objectives for the project we report on here were to work with SPEC to understand the characteristics of the in situ data set, identify problems and inconsistencies in the data, and to evaluate the applicability of the data to address the stated science goals of SPartICus. A meeting was held at the University of Utah in January, 2012, that combined the SPartICus and MACPEX teams to address common science themes and to compare the two data sets. The work supported by DESC007062 allowed us to use the SPartICus data for validation of several A-Train cirrus cloud retrieval data sets using the extensive in situ data (Deng et al., 2012).

Evaluation of the StormVEx data represents and additional objective effort of DESC007062. Understanding the complex microphysical processes that link air motions with the production of frozen precipitation in mixed phase clouds is an important but yet poorly understood process. This primary scientific objective of StormVEx was the motivating theme for the first deployment of the second ARM Mobile Facility (AMF2) to Steamboat Springs Colorado during the Storm Peak Lab Cloud Property Validation Experiment (StormVEx) from December 2010 through most of April, 2011. The AMF2 assets were arrayed from the valley floor near the town of Steamboat Springs to sites on the mountain nearly 1 km above the valley floor. On top of Mt Werner at an elevation of 2980 m, the Desert Research Institute Storm Peak Lab (SPL) collected in situ cloud, precipitation, and aerosol data. During the months of December, January and February, the University of Wyoming King Air research aircraft collected approximately 100 hours of in situ and remote sensing data in the airspace above Steamboat and the AMF2 in the NSF-supported Colorado Airborne Multi-Phase Cloud Study (CAMPS) campaign.

The campaign benefitted from one of the snowiest winters on record in the Northern Colorado Rocky Mountains and enjoyed cloud cover that exceeded 60%. Measureable snow was recorded on more than 75 days of the campaign with major snowfall exceeding 10 cm per day was recorded on approximately 40 of those days. Total measureable snowfall exceeded 800 cm. During this time, the major assets of AMF2 operated nearly flawlessly with no major downtime of the scanning W-Band Cloud Radar (SWACR). During the period of the experiment the SWACR collected terabytes of Doppler Spectra as well as volumetric radar reflectivity data in a volume that extended 10 km in all directions from the SWACR that included the complex terrain of the Park Range. Radiosondes were launched on a regular schedule from the valley by AMF2 and an intrepid cadre of local volunteers. Simultaneously, aerosol data were collected by the Aerosol observing system located on Christie Peak and at StormPeak Lab. Also at Storm Peak Lab, cloud droplets, ice crystals and snowflake particle concentrations were collected. In addition to the normal SPL staff, a team of graduate students from the University of Utah and the University of Washington maintained the SPL instrumentation in conditions that were often challenging.

A meeting was held at SPL in February, 2012 to discuss the StormVEx data set and to establish data analysis priorities for the coming years. Many challenges regarding data analysis were identified and discussed during the meeting and we used funding from DESC007062 to work through the action items to address those issues.

Our focus was to begin to characterize the PSD measurements collected at SPL. In addition, we devoted effort to evaluating the AMF2 data set and have focused initially on the SWACR data. Regarding the former objective, a subcontract was initiated with Dr. Gannet Hallar, Director of Storm Peak Lab, to focus on the SPL measurements collected during StormVEx. Our initial analysis (example in Figure 2) suggests that the SPL PSD data sets do indeed agree reasonably well with radar snowfall retrievals in several selected cases. However, we found inconsistencies in the PSD data that were likely due to poor counting statistics that arise because the sample volumes of the probes are too small and the concentrations of hydrometeors too sparse to produce good statistics at times for certain sizes. This issue was expected. We compared precipitation rates recorded nearby SPL to compare with precipitation rates derived from the SPL cloud and precipitation probes. With this comparison, we developed criteria that allowed us to better evaluate the PSD measurements collected at SPL. This work continues to the present day even though the funding for DESC007062 has long ceased.

References:

Deng, M., G. G. Mace, Z. Wang, and R. P. Lawson, 2012: Evaluation of several A-Train ice cloud retrieval products with in situ measurements collected during the SPartICus campaign, 2012: Submitted to Journal of Applied Meteorology and Climatology.

Matrosov, S, G. G. Mace, R. Marchand, M. D. Shupe, A G. Hallar and I. B. McCubbin, 2012: Observational evidence of ice hydrometeor habits and orientations influence on scanning polarimetric W-band radar measurements. Accepted in Journal of Atmospheric and Oceanic Technology.

The following publication abstracts were derived from DESC007062 funding and were acknowledged. The information in the abstracts summarize the technical results of this project:

Posselt, D. and **G. Mace**, 2014; The influence of parameter uncertainty on snowfall retrievals using Markov Chain Monte Carlo solution methods. Journal of Applied Meteorology and Climatology, 53, 2034-2057.

Collocated active and passive remote sensing measurements collected at U.S. Department of Energy Atmospheric Radiation Measurement Program sites enable simultaneous retrieval of cloud and precipitation properties and air motion. Previous studies indicate the parameters of a bimodal cloud particle size distribution can be effectively constrained using a combination of passive microwave radiometer and radar observations; however, aspects of the particle size distribution and particle shape are typically assumed to be known. In addition, many retrievals assume the observation and retrieval error statistics have Gaussian distributions and use least squares minimization techniques to find a solution. In truth, the retrieval error characteristics are largely unknown. Markov chain Monte Carlo (MCMC) methods can be used to produce a robust estimate of the probability distribution of a retrieved quantity that is nonlinearly related to the measurements and that has non-Gaussian error statistics. In this work, an MCMC algorithm is used to explore the error characteristics of cloud property retrievals from surface-based W-band radar and low-frequency microwave radiometer observations for a

case of orographic snowfall. In this particular case, it is found that a combination of passive microwave radiometer measurements with radar reflectivity and Doppler velocity is sufficient to constrain the liquid and ice particle size distributions, but only if the width parameter of the assumed gamma particle size distribution and mass–dimensional relationships are specified. If the width parameter and mass–dimensional relationships are allowed to vary realistically, a unique retrieval of the liquid and ice particle size distribution for this orographic snowfall case is rendered far more problematic.

Hammonds, K. D., **G. G. Mace**, and S. Y. Matrosov, 2014: Approximating the backscatter cross section of ice phase hydrometeor size distributions via a simple scaling of the Clausius-Mossotti factor. Journal of Applied Meteorology and Climatology, 53, 2761-2774.

One of the challenges that limit the amount of information that can be inferred from radar measurements of ice and mixed-phase precipitating clouds is the variability in ice mass within hydrometeors. The variable amount of ice mass within particles of a given size drives further variability in single-scattering properties that results in uncertainties of forward-modeled remote sensing quantities. Nonspherical ice-phase hydrometeors are often approximated as spheroids to simplify the calculation of single-scattering properties, yet offline calculations remain necessary to quantify these radiative properties as a function of size in discrete increments. In this paper, a simple scaling of the Clausius–Mossotti factor is used that allows for an approximation of the scattering and extinction cross sections for an arbitrary mass–dimensional power-law relationship of a nonspherical particle given a single T-matrix calculation. Using data collected by the University of Wyoming King Air in snow clouds over the Colorado Park Range, the uncertainty in forward modeled radar reflectivity to assumptions regarding mass–dimensional relationships is examined. This is accomplished by taking advantage of independently measured condensed mass and particle size distributions to estimate the variability of the prefactor in the mass dimensional power law. Then, calculating the partial derivative of the radar backscatter cross sections using the scaling relationships, an estimate is made of the statistical uncertainty in forward-modeled radar reflectivity. Uncertainties on the order of 4 dB are found in this term for the dataset considered.