Long-Term Regional Cloud Vertical Distributions Over the ARM Sites
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Year 1 Progress Report
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Project Status and Progress

Retrieval Implementation and Evaluation (J. Comstock, S. McFarlane)

We have implemented a new ground-based combined radar-lidar retrieval. In this retrieval, periods for which both radar and lidar exist are used to create tuned regression equations for periods where only radar or lidar data exists. We have implemented the retrieval at the Darwin ARM site for all available radar and lidar data (2005-2008) and have calculated heating rates associated with the retrieved cloud profiles. We have started implementing the cloud property retrieval on all of the available Manus data, and will then move to the Nauru site.

We are using two methods to evaluate the cloud property retrieval and associated uncertainty. In collaboration with Alain Protat (BMRC, Australia) and Julien Delanoe we are comparing our cloud property retrievals to those retrieved from their optimal estimation algorithm (Delanoe and Hogan, 2008). Initial results of this comparison are shown in Figure 1 below. Secondly, we are comparing the fluxes calculated from our retrieved cloud properties to those measured by the surface and TOA radiometers. Initial results show considerable improvement over standard ARM retrieval in thin clouds (Figure 2).

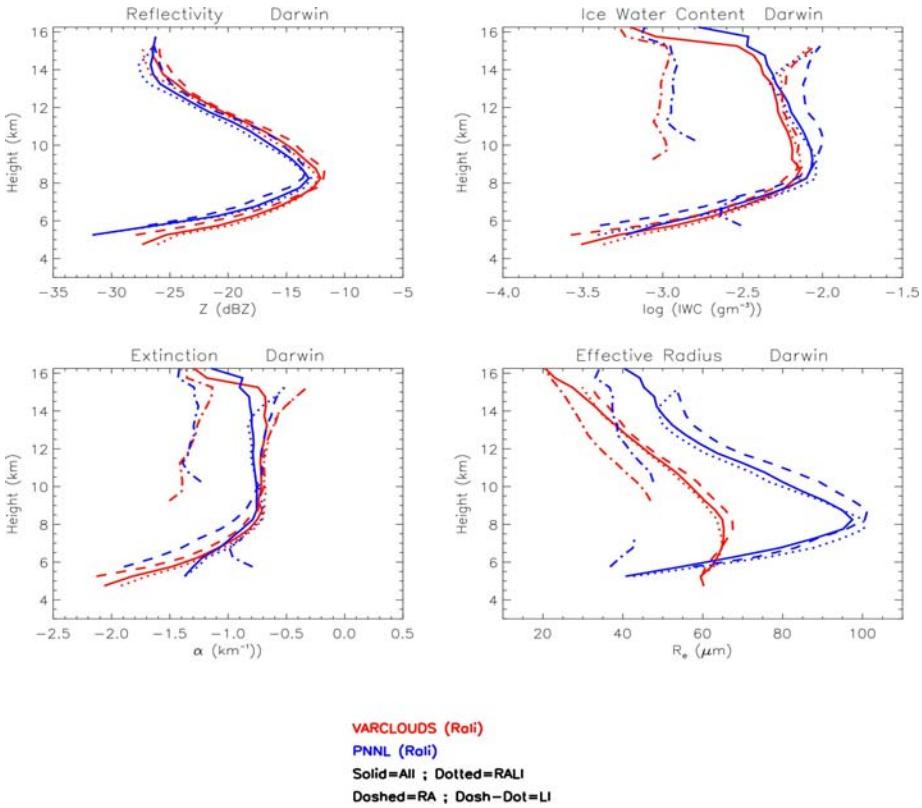

Figure 1. Comparisons between new PNNL combined radar-lidar retrieval (blue) and Delanoe optimal estimation retrieval (red). Line types represent type of clouds: all clouds (solid), radar and lidar detect cloud (dotted); only radar detects cloud (dashed); only lidar detects cloud (dash-dot). Results show good agreement except for effective radius in lidar-only clouds.

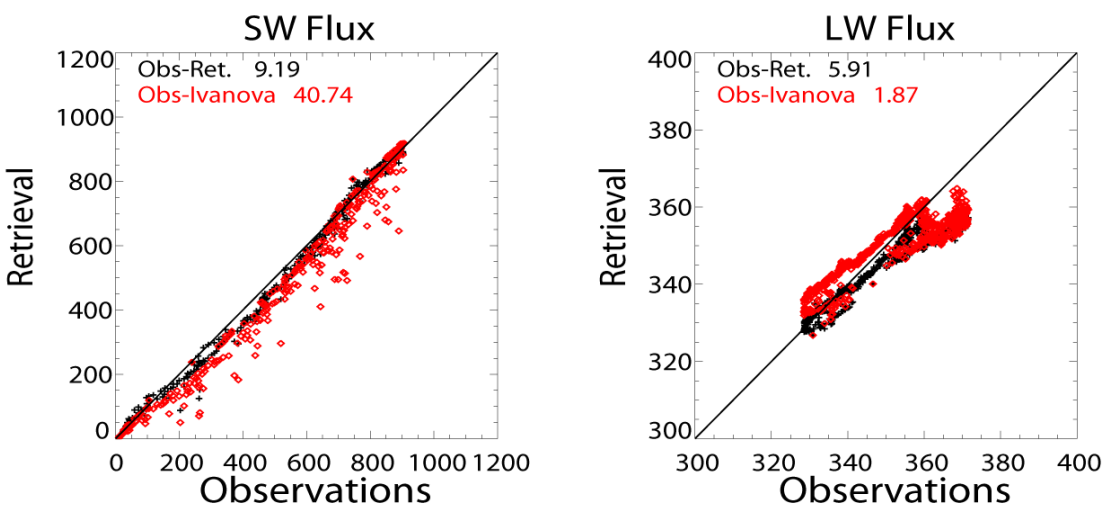

Figure 2. Scatter plot of calculated surface fluxes versus observed fluxes for a case at Darwin site. Black dots are new combined retrieval. Red dots are standard ARM retrieval. New retrieval shows much improved SW values for thin clouds compared to standard ARM retrieval.

Heating Rate Clustering and Classification (N. Beagley, S. McFarlane)

With funding from the Atmospheric Radiation Measurement (ARM) program, we started examining methods of classifying radar cloud profiles by cloud height and optical depth (similar to ISCCP classification method) to determine the typical cloud vertical structures seen in the ARM radar data. This research showed that the average heating rate profile at a given site could be reproduced by using the frequency of occurrence of cloud types at that site and the typical cloud vertical structures calculated from another site (Mather and McFarlane 2009). For the NEWS project, we are extending this work to bring in geostationary satellite data. The goal of this approach is to determine if we can use statistical methods and the long time series of high resolution ARM data to better predict vertical cloud/heating structure from passive satellite data and atmospheric state information. Previous observational studies have indicated that cloud layers are correlated vertically in different ways depending on the atmospheric state and that cloud radars can be used to determine cloud overlap statistics. A recent set of papers (Marchand et al. 2006, 2008) classified the atmospheric state at the ARM Southern Great Plains site using atmospheric reanalyses and saw differences in radar cloud structure between the states.

We plan to combine atmospheric state classification with cloud-class clustering to predict average heating rate profiles. First, we cluster the vertical cloud fraction data derived from radar data at ARM TWP sites to determine cloud classes (Figure 3) and calculate a statistical representation of the heating rate profile for each cloud class (Figure 4). We will use satellite data (OLR, optical depth, spatial variability) and environmental state data (T, RH, ω, winds) to create classification associating observations with cloud classes and assign a cloud fraction and heating rate profile to each observation based on associated cloud class. Then we will use a validation dataset (data not in the classification training set) to compare statistical cloud/heating rate profiles to the direct radar-derived cloud/heating profiles and examine the robustness at the other tropical ARM sites.

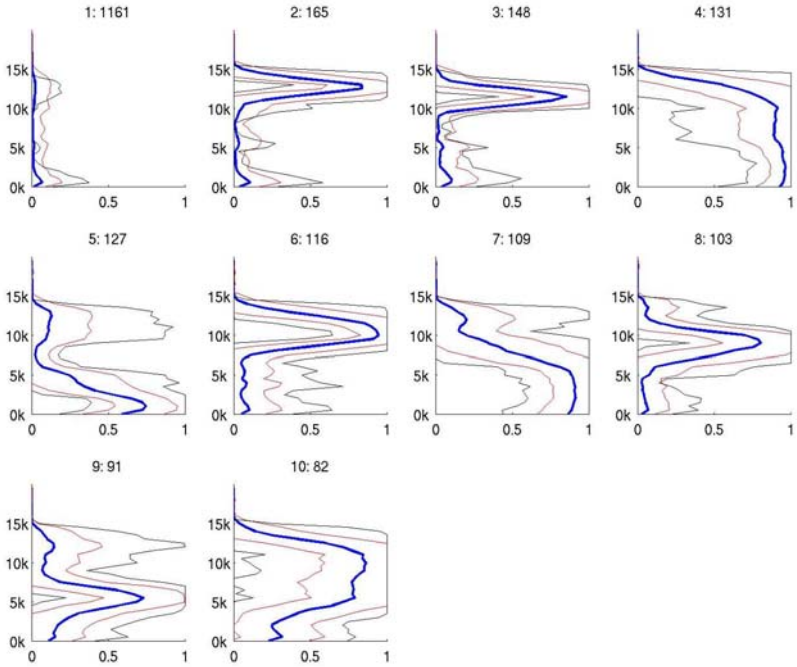

Figure 3. Initial set of cloud clusters. X-axis is frequency of cloud observed in a given layer over a 30-minute period. Y-axis is height. Title gives number of cluster and number of profiles in each cluster. Blue line is mean cloud frequency in given layer; red lines are mean +/- one standard deviations; red lines are 5th and 95th percentiles.

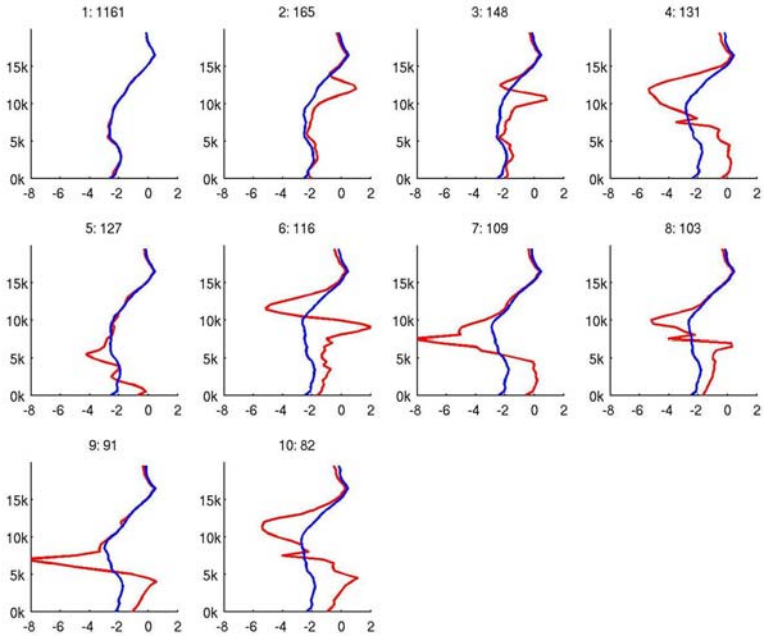

Figure 4. Longwave heating rates (K/day) associated with each cluster in Figure 3. Blue line is mean clear-sky heating rate; red line is mean all-sky heating rate.

The initial clustering methodology has been established, and we are performing sensitivity tests and establishing criteria to objectively determine the number of clusters, the optimal distance metric, and the parameters to include in the clusters. The next step is to use the satellite and environmental state information for classification.

MJO Analysis (Y. Wang, S. McFarlane)

We are also using our derived cloud and heating rate profiles to explore the relationship between diabatic heating and the phase of the Madden-Julian Oscillation (MJO). Comparisons between model and observational studies have indicated that the observed diabatic heating profile during the MJO is more top-heavy than that produced by models (Lin et al. 2004). However, the diabatic heating profiles used in this study were derived indirectly from radiosonde analysis. Analysis of surface radiation measurements (Wang et al. 2008) indicate that the signal of MJO can be clearly seen at the ARM Manus site, although not at the Nauru site. MJO periods have been identified in the time-series of ARM radar measurements at Manus, and we have begun analysis of the derived radiative heating profiles as a function of the phase of the MJO.

Collaboration

Previously, we performed an initial comparison of our heating rates to those retrieved from TRRM by Tristan L'Ecuyer (Figure 5). We have both substantially improved our cloud property retrievals (and our amount of processed data) since this initial comparison and plan to conduct a more comprehensive inter-comparison including extended time periods of comparison, evaluation of differences in clear-sky as well as all-sky profiles, and analysis of heating rate composites by cloud type.

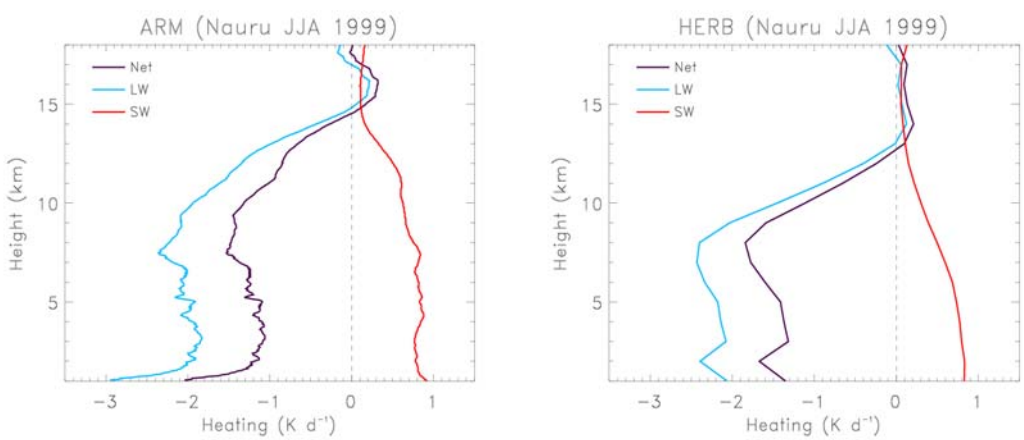

Figure 5. a) Nauru ARM and b) Nauru TRMM heating rate composites for JJA, 1999.

Additionally, we plan to develop collaborations with the CERES group (Weilicki and Kato). They currently produce a coarse-resolution vertical profile product based on passive satellite measurements, but are incorporating CloudSat and CALIPSO

information to improve estimates of cloud boundaries. We plan to do comparisons between the ARM and SARB atmospheric and surface radiation products for particular regions, to help evaluate and constrain these products.

Publications and Presentations

Comstock, J.M. and **S.A. McFarlane**, 2009: Effects of ice particle size on radiative fluxes using a combined remote sensing retrieval algorithm: results from TWP-ICE, *Poster presented at 19th Annual ARM Science Team Meeting, March 30- Apr 3, Louisville, KY.*

Fridlind, A. and co-authors (including **S.A. McFarlane)**, 2008: Joint ARM/GCSS/SPARC TWP-ICE CRM Intercomparison Study: Description, Preliminary Results, and Invitation to Participate, *Poster presented at Fall AGU Meeting, Dec 15-19, 2008, San Francisco, CA.*

Mather, J.H. and **S.A. McFarlane,** 2009: Cloud classes and radiative heating profiles at the Manus and Nauru ARM sites. *J. Geophys. Res.,* accepted, July 2009.

McFarlane, **S.A.,** N. Beagley, J.H. Mather, J. Flaherty, 2009: Determining Radiative Heating Profiles Through Classification and Clustering. *Oral presentation at AGU Joint Assembly, May 27, Toronto, Canada.*

Issues or Concerns

Due to a delay in getting my 2nd year of funding, I am somewhat behind schedule in implementing the cloud property retrieval and heating rates for all years of TWP data. I anticipate that I will need a no-cost extension in the 3rd year of the project.

Integration

To this point, I have not been heavily involved in the integration projects. At the last NEWS meeting I attended primarily the discussions on the Daily Timescale project. ARM data are uniquely suited for this project due to the high temporal resolution (1 min for most ARM observations). In previous work, we examined the diurnal cycle of clouds and heating rates using the cloud radar at the ARM Manus and Nauru sites. However there has not been much recent activity on that integration project. For the Annual and Longer Time Scales integration project, my analysis could be used to help validate the satellite datasets (at particular regions) which are being used to estimate the various components of the energy cycle. For example, in previous work (McFarlane et al. 200?) we used the cloud property retrievals from the radar to estimate the amount of SW absorption in the atmospheric column.

References

Delanoe, J. and R. Hogan, 2008, A variational scheme for retrieving ice cloud properties from combined radar, lidar, and infrared radiometer. *J. Geophys. Res.,* 113, D07204, doi: 10.1029/2007JD009000.

Lin, J., B. Mapes, M. Zhang, and M. Newman, 2004, Stratiform precipitation, vertical heating profiles, and the Madden-Julian Oscillation. *J. Atmos. Sci.,* 61, 296-309.

McFarlane, S.A., J.H. Mather, T.P. Ackerman, and Z. Liu, 2008: Effect of clouds on calculated shortwave column absorption in the Tropics. *J. Geophys. Res.,* 113, D18203, doi:10.1029/2008JD009791.

Wang Y., C.N. Long, and J.H. Mather, 2008, Convective Signals from ARM Surface Observations at Manus (1996-2006). *Subm. to Geophys. Res. Letts.*