Project Report (DE-FG02-03ER63536):

1. PI: Z. Wang, University of Maryland, Baltimore County,

2. Title of Research Grant: Using Radar, Lidar, and Radiometer measurements to Classify Cloud Type and Study Middle-Level Cloud Properties

3. Scientific Goal(s):

The project is concerned with the characterization of cloud macrophysical and microphysical properties by combining radar, lidar, and radiometer measurements available from the CART sites. To facilitate the production of integrated cloud product by applying different algorithms to the ARM data streams, we will improve our developed experimental cloud classification algorithm into an operational algorithm to provide cloud type as a VAP. Cloud type then can be used as a guidance to select an optimal retrieval algorithm for cloud microphysical property retrieval. This project also proposed to study midlevel clouds, especially mixed-phase clouds, by developing new retrieval algorithms using integrated observations at the CART sites. Midlevel clouds include ice, mixed-phase and supercooled water clouds. Among them, mixed-phase and supercooled water clouds are less understood, but have significant impacts on climate sensitivity. By applying developed retrieval algorithms to mixed-phase clouds observed at the CART sites, we hope to better understand mixed-phase cloud physics and improve mixed-phase parameterization in climate models.

4. Accomplishments during 2003-2004:
   - The development of an algorithm to study simple type mixed-phase clouds, altocumulus with ice virga, is finished and published in *J. Appl. Meteor.* **43**, 449-460, 2004.
   - The mixed-phase cloud algorithm is applied to long-term ARM observations at the NSA site.
   - The IDL code of an improved cloud classification algorithm based on the SGP CART site observation was delivered to ARM cloud translator during the 2004 ARM science team meeting. The initial results for 2000 were also distributed during the 2004 ARM Science Team Meeting.

5. Progress Description:

a) Mixed-phase cloud retrieval algorithm development and data analysis

We have finished the development of an algorithm to study a simple but important mixed-phase cloud, altocumulus with ice virga, by using ground-based active and passive remote sensors. The paper for this algorithm was published in *J. Appl. Meteor.* **43**, 449-460, 2004. Precipitating altocumulus cloud is a common type of mixed-phase clouds, especially in Polar region, and their easily identifiable structure provides a simple scenario to study mixed-phase clouds. First, the algorithm treats ice virga as independent ice clouds, and applies a lidar-radar algorithm to retrieve ice water content (IWC) and general effective radius (D_{ge}) profiles. Then an iterative approach is developed to retrieve

supercooled water cloud properties by minimizing the difference between observed IR radiances and DISORT calculated radiances at 12 selected wavelengths. The approach is applied to cases at both SGP and NSA CART sites. The case studies demonstrate the capabilities of this approach in retrieving necessary microphysical properties to characterize this type of mixed-phase cloud. The good agreement between visible optical depths derived from lidar measurement and those estimated from retrieved LWP and r_{eff} provides a closure test for the accuracy of mainly AERI-based supercooled water cloud retrieval.

The algorithm is being applied to long-term observations from the NSA site. Initial statistical results based on 40 cases were presented at this year science team meeting. The analysis for data up to 4-year is in progress, and results will be presented in next science team meeting.

b) Cloud classification algorithm improvement

We made significant progress in the improvement of cloud classification algorithm. Several important components of improved algorithm are finished. To provide cloud phase information when lidar depolarization measurements are unavailable, we study the possibility to use radar reflectivity factor and lidar backscattering coefficient for cloud layer phase determination. Based on 1-year SGP CART Raman lidar data, which provides depolarization measurements for cloud phase determination as a truth, we found the potential of the approach, especially using cloud temperature as additional information. To improve the flexibility of the code, we decide to combine rule-based and fuzzy logic-based classification methods. This combined approach also allows us to output confidence level for each cloud type.

The algorithm is coded in IDL, and we delivered a Vision 1 code for the SGP CART site to ARM cloud translator during 2004 science team meeting. The algorithm was tested based on data of 2000, and we distributed the initial results of 2000 in CD during the science team meeting. Now we are working on to apply the algorithm to more data at the SGP data and to modify it for the NSA data stream.

6. Figure Description:
   A case study of altocumulus with ice virga: Figure 1. Time-height display of Z_e (a), mean Doppler velocity (b) and MPL return power (c), and the retrieved IWC (d) and D_{ge} (e) of ice virga between 0400 and 1200 UTC on 18 January 2000 at the NSA CART site. Figure 2. The retrieved LWP (a) and r_{eff} (b) for the supercooled water part of the mixed-phase cloud case showed in the Fig. 1. In (a), LWP estimated from the MWR is given as dashed line. The comparison between visible optical depths for water dominated cloud layer derived from the MPL (solid line) and the LWP and r_{eff} (triangle symbols) is given in (c), and the optical depth of ice virga is shown as dashed line.

Cloud Classification examples: Figure 3. Time–height display of MMCR Ze, MPL return power, Raman lidar scattering ratio (LSR) and depolarization ratio, and classified cloud types for March 2000 IOP.

7. Refereed Publications

Wang, Z., D. Whiteman, B. Demoz, and I. Veselovskii, 2004: A new way to measure cirrus cloud ice water content by using ice Raman scatter with Raman lidar. *Geophys. Res. Lett.,* Vol. 31, L15101, doi:10.1029/2004GL020004.

Whiteman, D. N., **Z. Wang,** and B. Demoz, 2004: Substropical cirrus cloud extinction to backscatter ratios measured by Raman Lidar during CAMRX-3. *Geophys. Res. Lett*., doi:10.1029/2004GL020003.

Wang, Z., K. Sassen, D. Whiteman, and B. Demoz 2004: Studying altocumulus plus virga with ground-based active and passive remote sensors. *J. Appl. Meteor.*,**43**, 449-460.

Sassen, K., W. P. Arnott, D. O'C. Starr, G. G. Mace, **Z. Wang**, and M. R. Poellot, 2003: Midlatitude cirrus clouds derived from hurricane Nora: A case study with implications for ice crystal nucleation and shape. *J. Atmos. Sci.*, **60**, 873-891.

Sassen, K., **Z. Wang**, C. Platt, and J. Comstock, 2003: Parameterization of Infrared Absorption in Midlatitude Cirrus Clouds. *J. Atmos. Sci.*, **60,** 428–433.

8. Extended Abstracts

Wang, Z., D. N. Whiteman, B. Demoz, and I. Veselovskii, 2004: A new way to measure cirrus cloud ice water content by using ice Raman scatter with Raman lidar. P321, in *Proceeding of the 22nd International Laser Radar Conference*, Matera, Italy, July 12-16, 2004.

Wang, Z., K. Sassen, D. Whiteman, and B. Demoz, 2004: Studying Mixed-phase clouds with ground-based active and passive remote sensors. *Proceedings of the ARM Science Team Meeting*, 2004, New Mexico.

Wang, Z. and K. Sassen, 2004: An improved cloud classification algorithm based on the SGP CART site observations. *Proceedings of the ARM Science Team Meeting*, 2004, New Mexico.

Wang, Z., K. Sassen, D. Whiteman, and B. Demoz, 2003: Studying altocumulus plus virga with ground-based active and passive remote sensors. *Proceedings of the ARM Science Team Meeting*, 2003, Colorado.

9. Updated Status: none

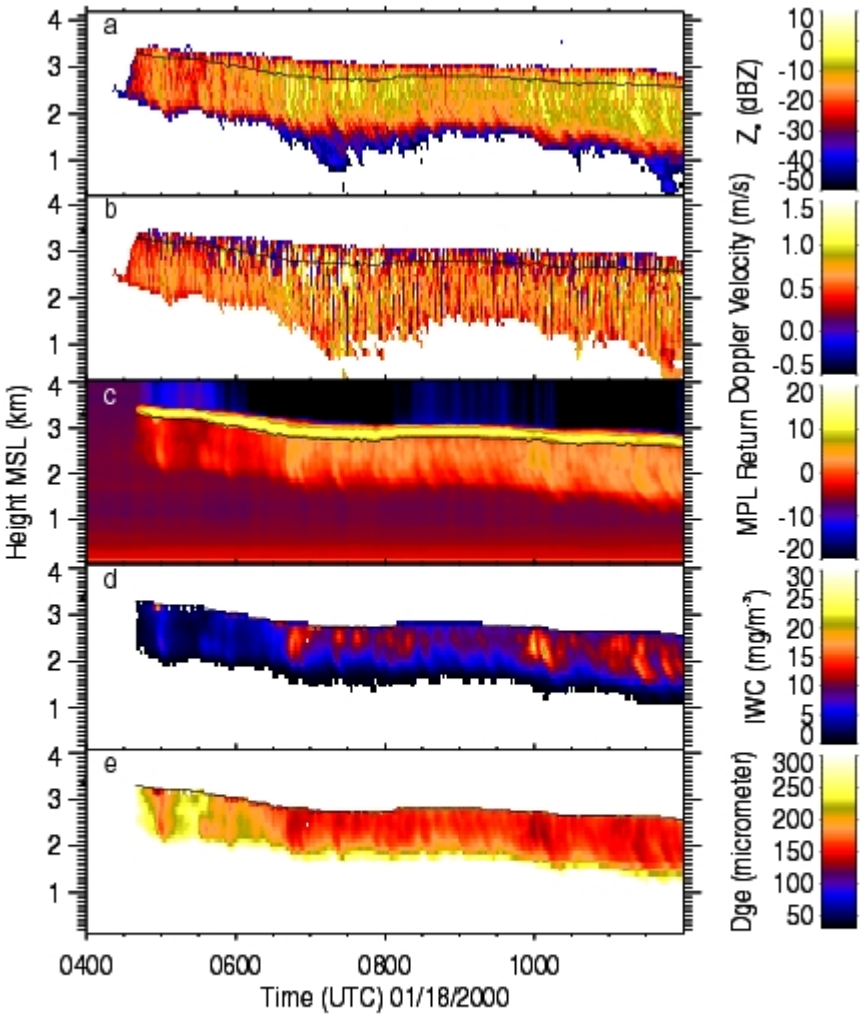

Figure 1. Z. Wang, University of Maryland, Baltimore County, 2004

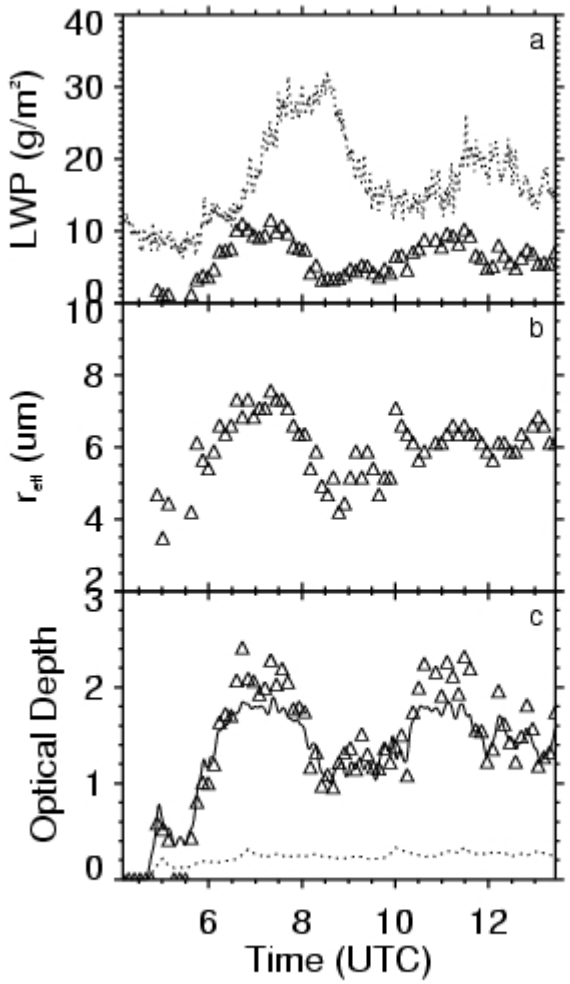

Figure 2. Z. Wang, University of Maryland, Baltimore County, 2004

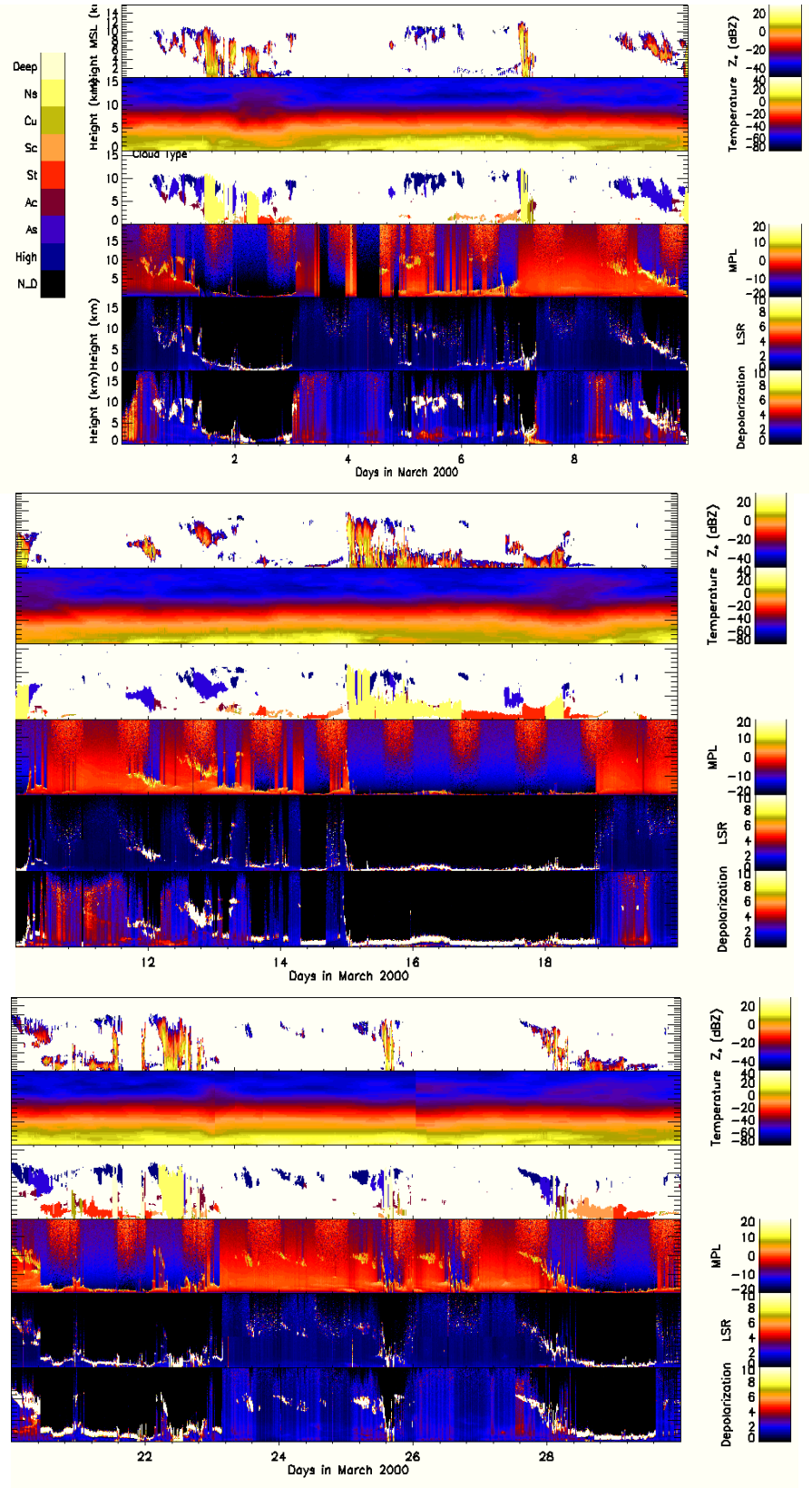

Figure 3. Z. Wang, University of Maryland, Baltimore County, 2004