

ARM PROGRESS REPORT**1. PI and Co-I Names and Affiliations**

Principal Investigator:

Bryan A. Baum
NASA Langley Research Center

2. Title of Research Grant:

The remote sensing of overlapping cloud properties using MODIS data and ARM CART site data.

3. Scientific Goal(s) of Research Grant

Our work addresses an outstanding problem of the cloud modeling and remote sensing community as related to ARM: the improvement of satellite- and ARM-derived multilayered cloud microphysical and macrophysical properties. While overlapping cloud layers occur quite frequently, ARM CART site analyses currently do not support operational retrieval of cloud macrophysical or microphysical properties under these conditions. We are developing and testing methodology to determine whether satellite imager pixels contain single-layer clouds or whether the pixels may contain potential cloud overlap in MODIS imagery. The groundwork for our research may be found in Baum et al. (2000a, b) and Baum and Spinhirne (2000), which is a set of papers that was published in the Journal of Geophysical Research in May 2000 (full references are provided below). The techniques have been tested using MODIS Airborne Simulator (MAS, King et al. 1996) aircraft data for a case of thin cirrus overlying a lower-level water phase cloud such as stratus. As MODIS data are now available, these methods, and the resulting EOS MODIS data products, are in the beginning stages of systematic comparison to overlapping cloud properties inferred from active lidar/radar measurements at the ARM CART sites.

Specific goals for which we anticipate rapid progress this year are to:

- a. develop methods for comparing instantaneous satellite data (high spatial resolution) with ground-based measurements (high temporal resolution).
- b. evaluate the ARM ground-based cloud profile products in conjunction with the MODIS-derived cloud products for all cloud cases, with an emphasis on cases involving overlapping cloud layers.

4. Accomplishments

- The papers that lay the groundwork for the collaborative research planned between MODIS and ARM scientists have just been published:

Baum, B. A., D. P. Kratz, P. Yang, S. Ou, Y. Hu, P. F. Soulen, and S-C. Tsay, 2000a: Remote sensing of cloud properties using MODIS Airborne Simulator imagery during SUCCESS. I. Data and models. *J. Geophys. Res.*, **105**, 11,767-11,780.

Baum, B. A., P. F. Soulen, K. I. Strabala, M. D. King, S. A. Ackerman, W. P. Menzel, and P. Yang, 2000b: Remote sensing of cloud properties using MODIS Airborne Simulator imagery during SUCCESS. II. Cloud thermodynamic phase. *J. Geophys. Res.*, **105**, 11,781-11,792.

Baum, B. A. and J. D. Spinhirne, 2000: Remote sensing of cloud properties using MODIS Airborne Simulator imagery during SUCCESS. III. Cloud overlap. *J. Geophys. Res.*, **105**, 11,793-11,804.

- Two additional papers describing advances in cirrus cloud modeling have been submitted for publication – see Item 7 below.
- Significant progress has been made towards improving the MODIS cloud retrieval products from their at-launch operational status (i.e., fixing the usual software problems associated with any new data processing initiative), with a special emphasis on the cloud thermodynamic phase determination and cirrus property retrieval.
- Software has been written to begin testing some preliminary MODIS overlapping cloud retrieval procedures and also to develop some methodology for comparison of the retrieved MODIS cloud parameters to surface lidar/radar ARM products.

5. Progress and accomplishments during last twelve months (or from beginning of the current effort whichever is shorter).

This is our first progress report as this is a newly funded project. At the time the proposal was submitted, the launch of the Terra platform, and hence MODIS, was still in the future. Fortunately, Terra was launched successfully and the MODIS instrument has been collecting data since the end of February. It is only recently

that the radiometric calibration has begun to stabilize to the degree where cloud products can be evaluated with any confidence. However, we are happy to report that significant progress that has been made regarding the maturation of the MODIS data processing.

The MODIS data processing, upon which our proposed work is critically dependent, is based upon successive stages of effort involving (a.) the cloud clearing process, (b.) determination of cloud thermodynamic phase (ice, water, or mixed phase), (c.) derivation of cloud heights, and finally (d.) inference of cloud optical thickness and effective particle size. In the MODIS world, separate data products are derived for each of these four processes. All algorithms have been designed to work independently of the other products except for the case of cloud clearing. One may choose to use another product if desired, but it is not a precondition.

At no time in this processing system, at least to date, is any attempt made to infer whether multilayered or overlapping clouds exist in any particular scene. As multilayered clouds occur in about half of all cloud observations, this is an area that we have chosen for focused effort. It is also true that there is precious little validation data available for comparison with the MODIS-derived overlapping cloud products at the current time.

To achieve our goals, our effort has been along the following lines:

- a. A MODIS cirrus retrieval team has been formed and has been working towards the continual improvement of the MODIS cirrus models used to derive cirrus optical thickness and effective particle size.
- b. The MODIS data processing group at the University of Wisconsin-Madison and at the NASA Goddard Space Flight Center has been working to fix operational data reduction problems in the global analyses of cloud properties. There is nothing like being overwhelmed with vast quantities of data from a new satellite imager. Specific to our ARM project, the specific data products that I have been working with over the past several months relate to the cloud thermodynamic phase and cloud height. A large part of the analysis of multilayered cloud systems is trying to determine the phase of each cloud layer.
- c. Currently we are writing software to analyze MODIS data collected from direct broadcast from the Terra platform to the Space Science Engineering Center at the University of Wisconsin-Madison. We were supposed to have a satellite dish installed on the roof of our building in Madison at the beginning of the year, but due to circumstances beyond our control, the anticipated installation date is now August 2000. Once the dish is installed, we will be receiving data directly from the EOS Terra platform for each overpass (day and night) over the central United States. The data will be converted to Level 1B at UW and subsequently cloud products will be generated locally. We anticipate that through the development of an off-line data production system using the direct broadcast MODIS data, we will be able to make rapid

progress towards developing retrieval methodology for overlapping cloud layers. As the MODIS data collected from direct broadcast will cover the central United States, and therefore the SGP ARM CART site, this is where our energy will be focused for the remainder of the year.

Concurrent with this effort to process MODIS data internally at UW, we are beginning to work with Dr. Ed Eloranta who was also recently added to the ARM team to develop the HSRL lidar for the purpose of measuring ice water content. As the HSRL is located in a trailer parked just outside our building, and Dr. Eloranta has graduate students who need to gain experience with validation activities, we are planning to operate the HSRL at times of MODIS overpass when conditions are favorable. Operation of the HSRL concurrently with the MODIS overpass, and consequent rapid production of MODIS cloud properties for the data, would provide immediate feedback. The HSRL provides the ability to infer the cloud thermodynamic phase, which is not currently part of the ARM CART site lidar/radar retrievals, the cloud layer boundaries, and additionally can provide an estimate of cloud optical thickness and particle size within limits. Our goal is to begin routine comparison of HSRL to MODIS cloud products beginning in August, assuming the dish is installed as planned. Our intent is to test various approaches for comparing potential MODIS multilayered cloud retrievals to ground-based observations before attempting to use ARM CART data, which we would like to do beginning next year. As progress is made on developing a workable system for implementing a new operational overlapping cloud retrieval algorithm for MODIS, the analysis will be extended to the ARM CART site. We also intend to collaborate closely with our colleagues Drs. Jay Mace, Xiquan Dong, and Eugene Clothiaux when we have the ability to develop overlapping cloud products from MODIS data. Ultimately, the overlapping cloud routines developed for MODIS will become part of the operational data reduction effort located at NASA Goddard Space Flight Center.

- 6. As appropriate attach one or so electronic figures with paragraph discussions highlighting current research. Label with PI name, affiliation, and year. We will use these in presentation materials.**

NOTE: there should be a separate PowerPoint file that contains two images.

- 7. List all *refereed* publications either submitted or published during the *current* grant FY that acknowledge DOE ARM support.**

Our project was initiated earlier this year, and to date two papers have been submitted for publication; one is now in press. Additionally, as MODIS cloud product generation is becoming more settled and mature, we expect to begin documentation of MODIS cloud products and the initial validation results.

Yang, P., B.-C. Gao, B. A. Baum, W. Wiscombe, Y. Hu, S. Nasiri, A. Heymsfield, G. McFarquhar, and L. Miloshevich, 2000: Sensitivity of cirrus bidirectional reflectance to vertical inhomogeneity of ice crystal habits and size distributions for two MODIS bands. In press, *J. Geophys. Res.*

Yang, P., B.-C. Gao, B. A. Baum, Y. X. Hu, W. Wiscombe, M. I. Mischenko, D. M. Winker, and S. L. Nasiri, 2000:
Asymptotic solutions of optical properties of large particles with strong absorption. Submitted to Applied
Optics.

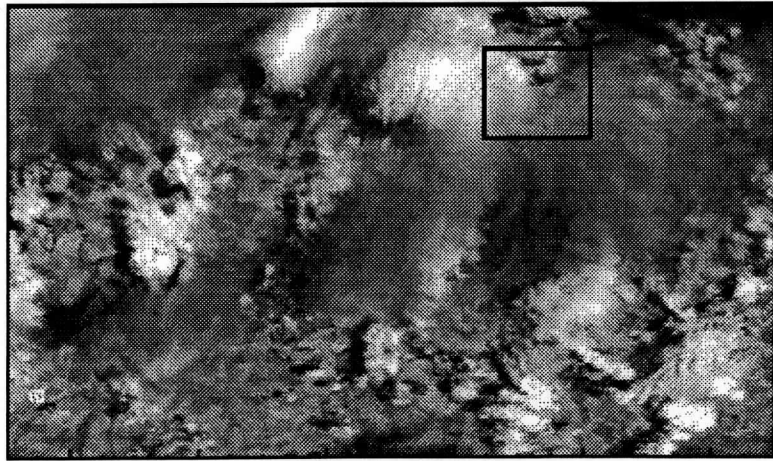
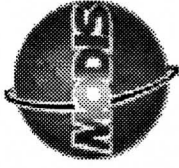
- 8. List all published (either paper or web-based) extended abstracts in the current FY that acknowledge DOE ARM support. Two copies of each should accompany the progress report*.**

The only extended abstract to date was the one we developed for presentation at the ARM Science Team Meeting earlier this year.

- 9. Please update us on the status of submitted referred publications from the previous FY progress report.**

NONE, as this is our first progress report.

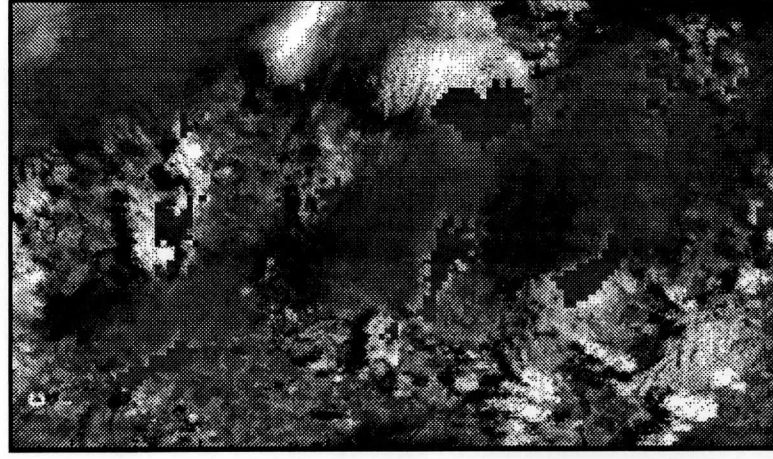
Detection of Overlapping Cloud Pixels in MAS Data



1.63 μm



1.90 μm

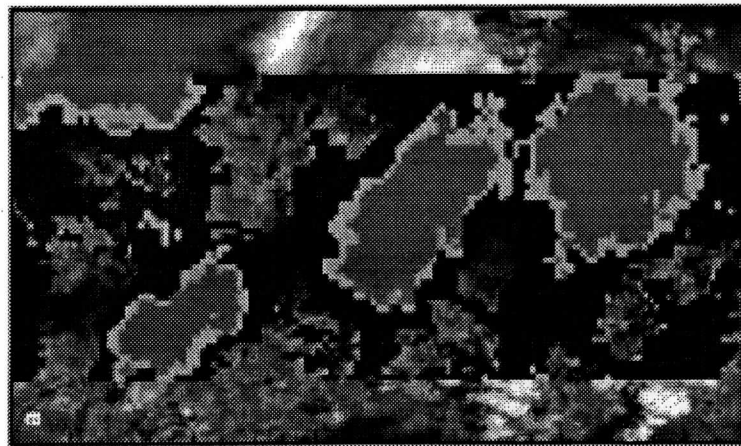


Cloud Overlap Detection

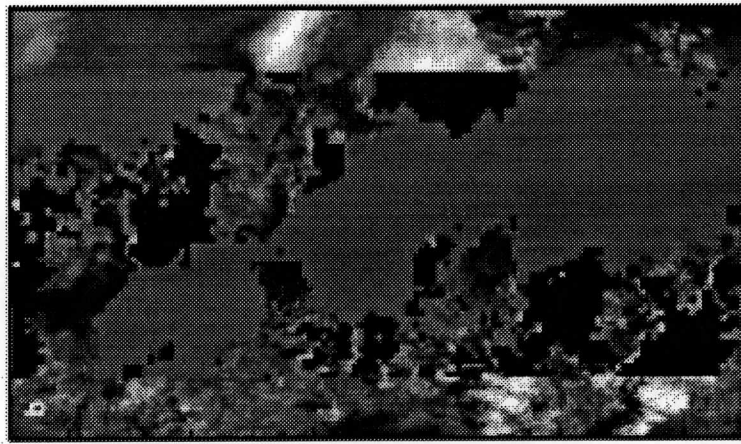
MODIS Airborne Simulator (MAS) image recorded on April 21, 1996, over Oklahoma during ER-2 Flight Leg #11 between 1959 and 2002 UTC. (a) The scene at 1.63 μm ; (b) the scene at 1.90 μm , and (c) the results from application of the MAS overlapped cloud detection algorithm. The scale of the image is 37.5 km cross track by 50 km along track.

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July, 2000

Thermodynamic Cloud Phase Retrieval using MAS data

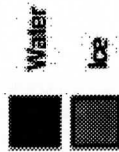
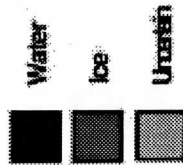


Trispectral IR Method



Trispectral IR Method with additional VIS/NIR Channels

Discrimination of cloud thermodynamic phase from application of (a) the MODIS IR trispectral algorithm based on the 8.5-, 11-, and 12- μm bands, and (b) the MODIS IR trispectral method augmented by data from the 0.65-, 1.63-, and 1.90- μm bands. The algorithms are applied to a MODIS Airborne Simulator (MAS) image recorded on April 21, 1996, over Oklahoma during ER-2 Flight Leg #11 between 1959 and 2002 UTC (same scene as on cloud overlap detection slide, with thin cirrus contrail in center of image). The scale of the image is 37.5 km cross track by 50 km along track.



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