Semi-annual Report
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Abstract

Our major achievements of the past six months were: (i) the upgrade of the MODIS Airborne Simulator (MAS) and radiometric characterization in a thermal/vacuum chamber, (ii) the analysis of MAS instrument data acquired in the thermal/vacuum chamber, to be used in temperature corrections for in-flight and ground calibrations, (iii) the preparation for and participation in an April cirrus cloud deployment known as SUCCESS (Subsonic Aircraft Contrail and Cloud Effects Special Study), which included a quick-look data processing system for use in the field, (iv) the delivery and efficiency improvement of our MODIS cloud retrieval algorithms, and (v) an initial attempt at understanding the cloud inhomogeneity effects on retrieved parameters.

I. Task Objectives

With the use of related airborne instrumentation, such as the MODIS Airborne Simulator (MAS) and Cloud Absorption Radiometer (CAR) in intensive field experiments, our primary objective is to extend and expand algorithms for retrieving the optical thickness and effective radius of clouds from radiation measurements to be obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS). The secondary objective is to obtain an enhanced knowledge of surface angular and spectral properties that can be inferred from airborne directional radiance measurements.

II. Work Accomplished

a. MODIS-related Algorithm Study

After the delivery (October 1995) of our MODIS Beta-3 cloud retrieval algorithm software for integration and testing, Menghua Wang further improved the efficiency of the retrieval code. This was done by generating new lookup tables, modifying/rewriting, and creating/replacing subroutines in the cloud retrieval code. The efficiency of the cloud retrieval algorithm has been improved by a factor of more than 6, as shown in the following results. CPU times for 1 scan-cube of MODIS data (there are 100 scan cubes in a granule) are:

Compiler option	*Before*	*After*
Without optimization	183 s	25.8 s
With optimization	111 s	17.5 s

The initial MODIS *v1* cloud retrieval algorithm was delivered to and accepted by SDST on 6 May 1996, following by a couple of modifications (e.g., package files of README and Packlisting) to satisfy SDST requirements. We intend to test the MODIS algorithms interface and flow with the "MAS to MODIS" data sets. For the robustness of the codes, work is also underway to include the capability of dealing with day and night mode, bad detector signals, variable scan and pixel size, etc. The inclusion of the 3.7 µm channel into the present MODIS cloud retrieval algorithm (0.66, 1.6 and 2.1 µm) is nearly completed. By adopting the current code structure, few subroutines were added to remove the 3.7 µm thermal contribution using information from the 11 µm measurements. Therefore, the unique feature of applying asymptotic theory in our retrieval algorithm is retained. Reflectance lookup tables for 0.66, 1.6, 2.1, 3.7, and 11 µm channels in MODIS data format have been generated. Figure 1a shows the contribution of both solar and thermal infrared radiation to the outgoing 3.7 µm radiance at the top of atmosphere for cloud and surface. Figure 1b illustrates the theoretical relationship of reflection function between 0.664 and 3.725 µm for various values of cloud optical thickness and effective particle radius for θ_0 = 26°, θ = 40°, and φ = 42°, in which MAS measurements from ASTEX (22 June 1992) over marine stratocumulus clouds are superimposed.

The present MODIS cloud retrieval algorithm is based on the assumption that clouds contain uniform particle size in each vertical column. In turn, the retriev-

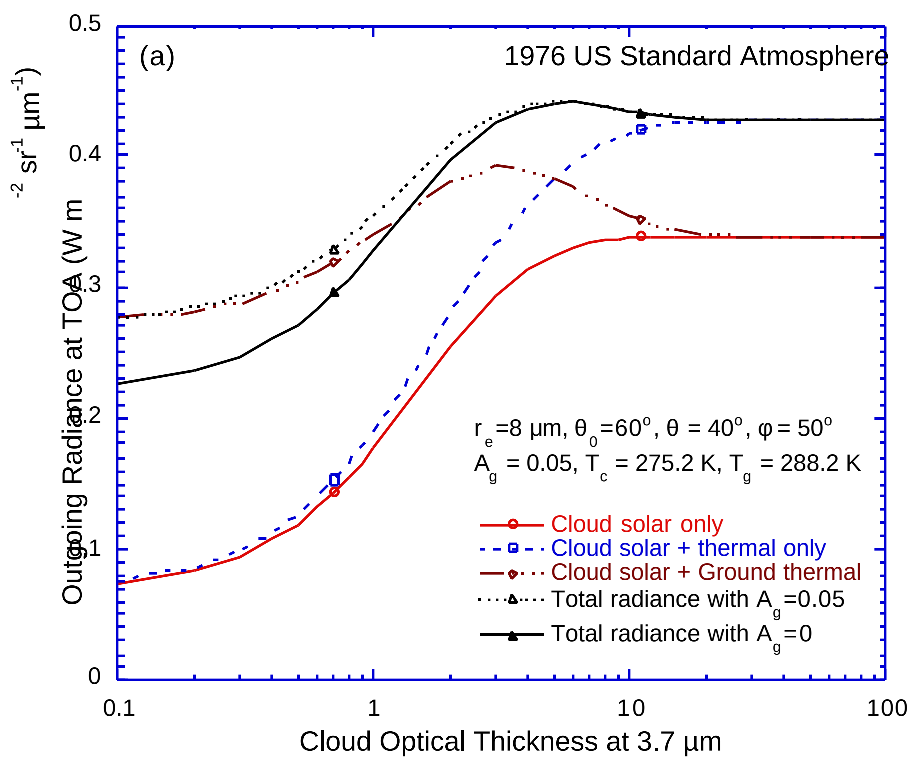

Figure 1a. Effect of solar and infrared radiation on the upwelling radiance at 3.7 µm as a function of optical thickness

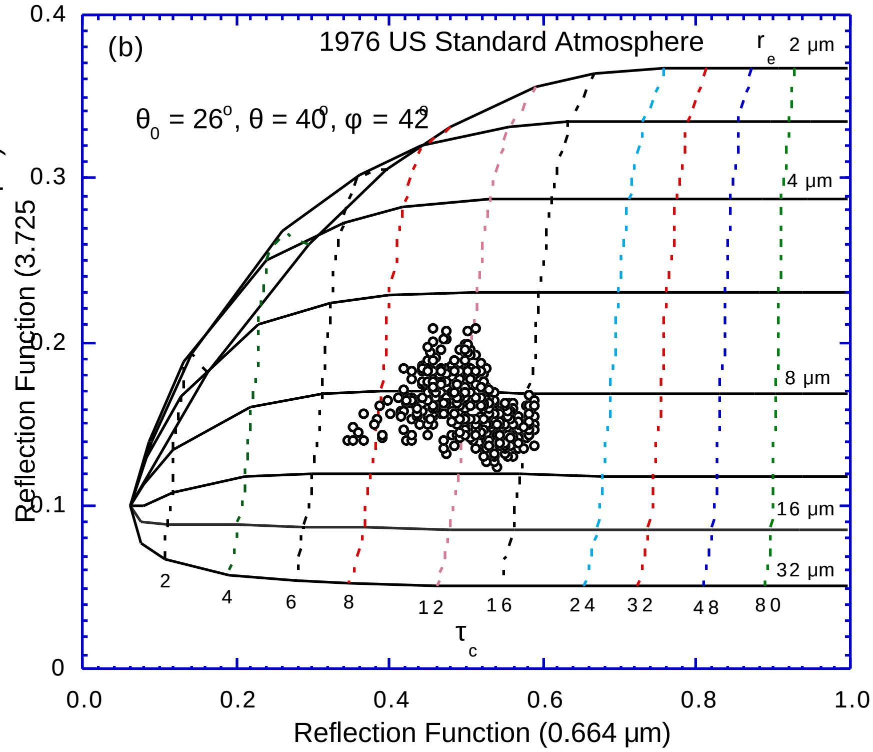

Figure 1b. Theoretical relationship of reflection function between 0.664 and 3.725 µm for various values of cloud optical thickness and effective particle radius. Data obtained from the MODIS Airborne Simulator on 22 June 1992.

als of particle size from each pair of non-absorbing and absorbing channels (e.g., 0.66/1.6 µm *vs* 0.66/3.7 µm) should yield identical results. Working on real world data, however, it is often observed that variable sizes are retrieved due to cloud vertical inhomogeneity. The cloud absorbing channels (e.g., 1.6, 2.1 and 3.7 µm) used in the algorithm have different water vapor absorption characteristics, in terms of which photons received by the sensor at a particular geometry should associate with different vertical weightings. Making the first attempt at understanding vertical contributions, Steve Platnick derived the photon vertical "weighting" functions from both Adding/Doubling and Monte Carlo methods.

Figure 2 depicts the relative depth of penetration of reflected photons from a cloud with a total optical thickness $\tau_c = 10$, effective radius $r_e = 10$ µm, and cosine of the solar zenith angle $\theta_0 = 0.85$. Curves represent common solar MODIS/MAS channels used in cloud remote sensing. The more absorbing channels (e.g., 3.7 µm) have a greater weighting towards the top of the cloud, whereas the non-absorbing channels (0.66 µm) have some weighting even at the bottom of the cloud. The area under each weighting curve should yield unity. Studies of "correcting" cloud inhomogeneity effects on particle size retrievals are currently underway.

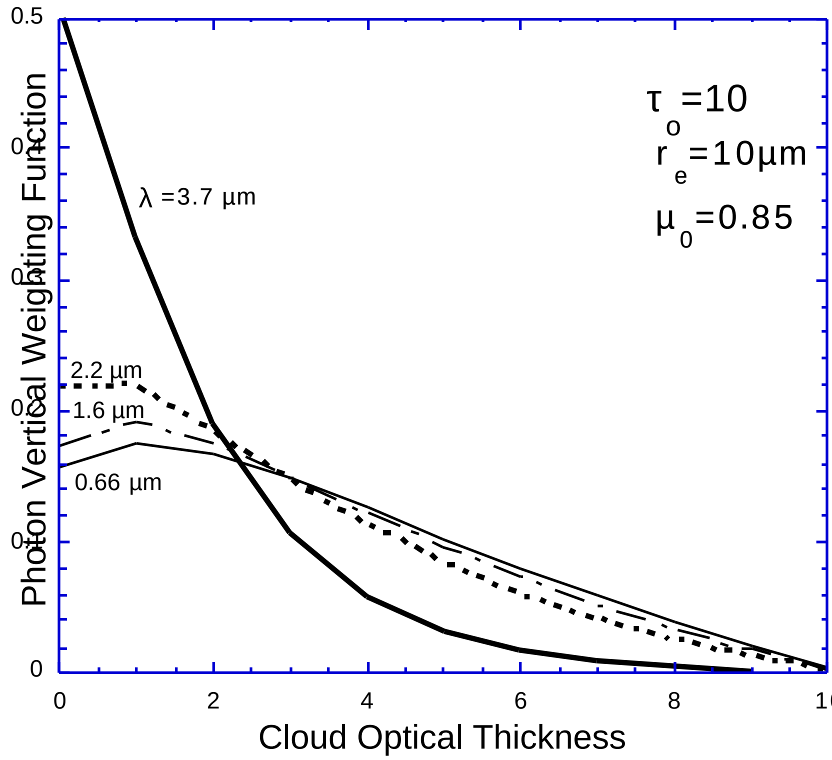

Figure 2. Theoretical relationship of reflection function between 0.664 and 3.725 µm for various values of cloud optical thickness and effective particle radius. Data obtained from the MODIS Airborne Simulator on 22 June 1992.

b. MODIS-related Instrumental Research

The MAS returned from Dædalus on March 3rd with many modifications and improvements. On the MAS optics: (i) both mirrors in the Pfund assembly (field stop) were re-coated and re-aligned; (ii) all seven spectrometer mirrors were re-coated; (iii) the first and second dichroics were replaced; (iv) the port 2 grating was replaced (the port 1 grating was determined to be working properly, and was not replaced); (v) a new primary folding mirror and a new primary parabola were installed (the old ones were re-coated as spare parts); and (vi) the rotating scan mirror was re-coated. On the MAS electronics: (i) heaters were added to the outside of the port 2 pre-amplifier housing and thermostatically controlled to maintain a temperature of 28° C (± 1°) inside the housing (cold test by Dædalus down to -30°C); (ii) this pre-amplifier housing was also thermally isolated from the dewar jacket to prevent uneven heating of the dewar; (iii) the port 1 detector array is now temperature stabilized to 29°C (± 1°) and was cold tested down to -30°C (the blue channel was not yet installed at this time); (iv) the port 2 pre-amplifier was repaired and the gains for channels 10, 16, 19, 20 were lowered to match the rest of the array; (v) the amplifiers for channels 10-13 were replaced; and (vi) the voltage regulator that supplies all the pre-amplifiers, and some related connectors, was replaced (this might have been the source of the port 4 transients that occurred during and after the Brazil deployment).

As a result of these MAS upgrades, Dædalus reported that signal levels have increased an average of 132% for port 1, 51% for port 2, and 112% for port 3 (port 4 was not measured due to lack of time, but a big improvement is expected). The "TEMP2" thermistor was found to be physically detached from its location on the port 3 optics housing; making its data meaningless. This may have happened around the time of the GSFC chamber tests, but there is no way of knowing for sure. Several of the heater control thermistors were also detached, which means the head heaters were not being properly regulated. These have all been re-attached with a new type of epoxy. Two more new "TEMP" values will be added to the MAS housekeeping (inside of the port 2 pre-amplifier housing and port 1 array mount). Aerodynamic modeling of the cavity in the rear of the ER-2 superpod, where the MAS head is mounted, shows a sizable air blast. This undoubtedly increases cooling of the head and probably explains some of the incongruities in the Goddard chamber tests (possibly some thermal IR calibration errors as well). A strake (air dam) has been designed to fit in front of the MAS aperture on the superpod to reduce the airflow inside the cavity. This was installed before the SUCCESS deployment. The MAS head now has eight additional thermistors installed for the first test flight to record the results.

After the SUCCESS deployment, the modifications of the MAS spectral bands in ports 1 and 3 were performed at Ames by Dædalus personnel. The new gains in the port 1 silicon array (with the new blue channel) have been set and all channels have been spectrally calibrated at the same time. The pre-amp gains were set close to the levels we had before the recent optical refurbishment, which had resulted in some saturation over very bright clouds during the SUCCESS mission. The port 3 array (covering 2.88-5.36 µm) has been shifted one full-band toward longer wavelengths (covering 3.04-5.52 µm), given the basic criteria that the old channel-31 band edges (3.67-3.82 µm) must be preserved (now channel-30). The rationale for the change was that the old channel-26 (2.96 µm) was extremely noisy due to detector inefficiency at this short wavelength. Although we may not have much better luck at the new 5.4 µm channel, as the InSb detectors are equally poor in this region, we should have more incoming energy to work with. This work was accomplished by rotating the grating, rather than moving the dewar, as originally planned. Dædalus also gained some insight as to the nature of the spectral drift we saw in this port over time, and may recommend a mechanical modification later. Pavel Hajek and Dan LaPorte now have the Bomem FTIR source fully operational, which will provide very precise characterization of the ports 3 and 4 bands. Future work of the Ames team will include pursuing the MODIS orbital blackbody design, determining its suitability for MAS, and developing an onboard optical calibration source for the MAS. Dædalus is also working with FOSTEC, Inc. to determine the mechanical feasibility of incorporating their fiber-optic light panel into the MAS fore-optics. We would have to design a stable lamp assembly to illuminate the fiber bundle, but we may be able to cannibalize the AVIRIS design for this.

To further support our scientists in future field campaigns, Ward Meyer and Jason Li developed a self-contained hardware and software package for the SGI (redback) workstation for MAS deployments. In collaboration with scientists at the University of Wisconsin - Madison, an IDL routine package was created to produce quick-look products from MAS data after each flight. Unlike the quick-look procedure developed earlier, the new one presents MAS data for multispectral bands in compact GIF files and the ER-2 flight track is overlaid over a fine resolution topographic map with time codes along the aircraft ground track. This is an integral part of the quick-look products produced for the SUCCESS field campaign (see Fig. 3).

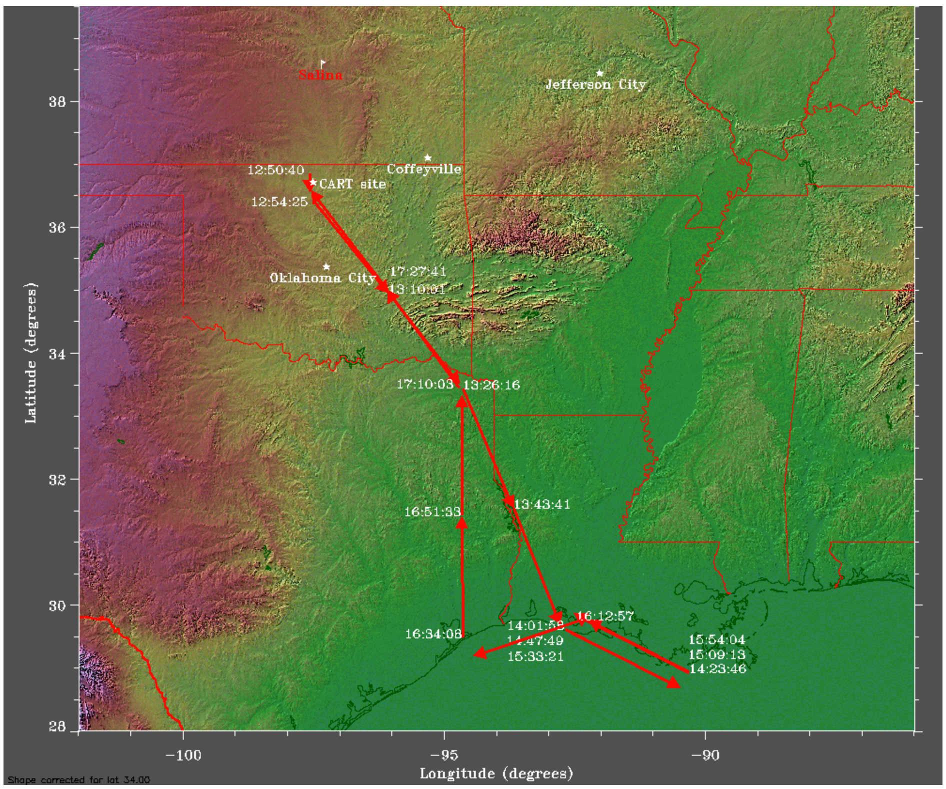

Figure 3. ER-2 ground track superimposed on topography map of the mid-western United States (9 April 1996).

c. MODIS-related Services

<u>*SUCCESS experiment*</u>

The SUCCESS (SUbsonic aircraft Contrail and Cloud Effects Special Study) was a focused field experiment designed to better understand the radiative properties of cirrus and of contrails and the potential effects of subsonic aircraft on these clouds and heterogeneous chemistry. It was conducted at Salina, KS (8 April - 10 May 1996) and at NASA Ames, CA (10-15 May 1996) and involved close collaboration between NASA, DoE, and many universities, as well as private sectors. The strategy for this experiment in the vicinity of U.S. Southern Great Plains included spaceborne remote sensing (NOAA-14 polar orbiting satellite), high altitude remote sensing (NASA ER-2 aircraft at ~20 km), tropospheric *in situ* measurements (NASA DC-8, B-757 and T-39, and DoE Egret and Twin Otter aircraft), and surface remote sensing and ground truth observations at the CART site (Cloud And Radiation Testbed, DoE).

During 8-15 April 1996, Si-Chee Tsay and Jason Li participated in the SUCCESS deployment for MAS science support; and later this role was taken over by the University of Wisconsin group (Steve Ackerman and Liam Gumley). For the SUCCESS experiment, 16 research flights were conducted by the ER-2 aircraft, which flew about 80 flight hours with about 70 hours of MAS data acquired. Highlights of these flights are as follows:

- Preliminary MAS quick-look results showed that the instrument was functioning well and acquired rich features of cirrus clouds (thin to thick), contrails, convective activities, and surface/water under clear-sky conditions.

- Nine of the ER-2 missions were conducted under the NOAA-14 satellite overpass, in which validation measurements were provided by *in situ* aircraft (all) and surface CART site (two times).

- Two coordinated flights between the ER-2 and all *in situ* aircraft were conducted over the CART site for collecting contrail (produced by B-757, as control case) data.

- Two coordinated flights between the ER-2 and DC-8 were conducted in the west coast of the US for collecting cirrus clouds and contrails over water, in which numerous ship tracks were also observed.

- Eight of the ER-2 missions were conducted over the CART site, in which three of them were under clear-sky conditions and the rest had cirrus clouds and contrails that were profiled by *in situ* aircraft.

Figure 4 shows an RGB composite (i.e., 1.88, 1.61, and 0.667 µm, respectively) of MAS data for 8 April 1996, which clearly demonstrates the rich features of cirrus clouds (thin to thick, upper part to center), low-level clouds (center-right in white), contrails and their shadows (center in red and black, respectively), surface vegetation (background), and mountain snow and lake (lower part in blue and black, respectively).

Meetings

1. Si-Chee Tsay attended the US-Japan Workshop on Arctic Research, held in Fairbanks, Alaska on 5-8 February 1996 and presented a NASA/MTPE EOS-

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Figure 4. MAS red-green-blue composite (1.88, 1.61, and 0.667 µm) acquired on 8 April 1996.

MODIS description of radiation measurements in the Arctic;

2. Michael King and Si-Chee Tsay attended the FIRE science team meeting in Williamsburg, Virginia on 13-15 February 1996 and presented an update on

EOS as well as preliminary results acquired during the ARMCAS campaign;

3. Michael King attended the NPOESS Workshop at the University of Maryland on 27-29 February 1996 and participated in the Integrating Panel (Jerry Mahlman, chair) discussions on the NPOESS program in light of developments, plans, and capabilities being developed and planned as part of EOS;

4. Michael King, Steve Platnick, Si-Chee Tsay and Menghua Wang attended the CERES science team meeting held at NASA Goddard Space Flight Center on 13-15 March 1996, and Steve presented results analyzed from the CERES AVHRR test data for the retrieval of cloud radiative and microphysical properties;

5. Si-Chee Tsay attended the TARFOX planning meeting at NASA Wallops Flight Facility on 18-20 March 1996 and presented MAS and CAR instrumentation and preliminary results acquired during the SCAR-B campaign;

6. Michael King, Qiang Ji, Jason Li and Si-Chee Tsay attended the SCAR-B data workshop at NASA Goddard Space Flight Center on 21-22 March 1996 and presented preliminary results of aerosol, CCN, and radiation measurements acquired during the SCAR-B campaign;

7. Michael King, Si-Chee Tsay and Menghua Wang attended the Aerosol Remote Sensing Workshop in Washington, DC on 15-19 April 1996 and participated in all panel discussions (Michael King chaired the validation panel);

8. Steve Platnick attended the Monterey Area Ship Track Experiment workshop at Monterey on 15-19 April 1996 and presented ship track analysis of MAS data and discussed collaboration of papers for MAST;

9. Michael King, Robert Pincus, Steve Platnick, Si-Chee Tsay and Menghua Wang attended the MODIS Science Team meeting at NASA Goddard Space Flight Center on 1-3 May 1996 and participated all panel discussions;

10. Michael King and Si-Chee Tsay attended the EOS Validation workshop at NASA Goddard Space Flight Center on 6-8 May 1996 and participated in all panel discussions;

11. Michael King attended the Investigators Working Group meeting in Greenbelt on 13-15 May 1996 and participated in all panel discussions;

12. Si-Chee Tsay attended two informal meetings in Taiwan on 19-25 June 1996 with the Central Weather Bureau and National Taiwan University and discussed possible collaborations of using EOS data;

13. Michael King and Si-Chee Tsay attended the first ADEOS/GLI Science Team meeting in Hakone, Japan on 26-28 June 1996, and Michael King presented proposed GLI research objectives and participated in all panel discussions.

Seminars

1. Wang, M., “Atmospheric Corrections and Ocean Color Sensing,” Physics Department, University of Maryland-Baltimore County, Baltimore, MD, 27 March 1996;

2. Platnick, S. E., “Cloud Radiative Transfer and Remote Sensing,” Physics Department, University of Maryland-Baltimore County, Baltimore, MD, 24 April 1996;

3. Platnick, S. E., “Remote Sensing of Marine Stratocumulus Clouds and Ship Tracks,” Department of Meteorology, University of Utah, Salt Lake City, UT, 26 June 1996.

III. Data/Analysis/Interpretation

a. Data Processing

During the week of 18-24 March, Tom Arnold, Steve Platnick and NASA Ames personnel conducted four cold chamber tests on the MAS, three with heaters on and one with heaters off. Preliminary analyses of tests 1-3, and comparing these results to previous chamber calibration work at Goddard, show that the thermal sensitivity of ports 1 and 2 calibration is reduced significantly (to less than 5%) after the MAS upgrades. However, the calibration changes as a function of temperature are more complex. More testings are required in the future to check the repeatability and to simulate various flight temperature regimes in the chamber. After discussions with Jeff Myers and Mike Fitzgerald at NASA Ames Research Center, we found that the subtraction of a 3000 count offset from the recorded cold blackbody counts during the visible and near-infrared calibration procedure is not necessary. In addition, the emissivity correction for infrared calibration developed by Chris Moeller requires the unpacking of the scan head count from the Level-0 data. These correction schemes have been implemented and applied to the processing of Level-1B data from ARMCAS (June 1995—Alaska) and SCAR-B (August-September 1995—Brazil) campaigns.

The MAS 50-channel Level-1B processing software has been completed by Paul Hubanks. However, only a few flight lines of ARMCAS and SCAR-B campaigns have been processed to Level-1B HDF files. This is largely due to SDST hardware problems: Exabyte Tape Drive failure since April and Exabyte Tape Drive problem on the host SGI platform, both not resolved until June 7th 1996. In the meantime, new hardware (earmarked for MAS processing) have been ordered for SDST and will arrive soon. If that all goes well with the setup of hard drives, Exabyte tape drives, etc., on ANCHOR (the new MAS Processing Platform), the increase of processing speed is expected.

When analyzing a large volume of remote sensing data, such as those acquired from the hyperspectral and high spatial resolution MAS, visualization tools are of vital importance to scientists. Working closely with Dr. Fritz Hasler's group, Jason Li recently ported the Interactive Image SpreadSheet (IISS) software to both SGI computers in the cloud retrieval group (redback and cerpa). Another commercial image processing package (ENVI), developed and promoted by Ames Research Center, was also installed on these computers. Measurements obtained from MAS (8/18, 8/25, 9/1 for fires, smoke, and aerosol-cloud interaction), CAR (9/18 for whole-surface imagery) and GOES-8 (8/25) sensors were demonstrated using both IISS and ENVI tools at the SCAR-B science workshop, held recently at Goddard. Both packages exhibit strong capabilities in the area of image visualizations and analysis.

The post SCAR-B calibration of the CAR was conducted by Tom Arnold using the 48-inch integrating hemisphere as the source. Due to some apparent changes in the actual output of both 48-inch and 6-foot Goddard integrating sources, as pointed out by John Cooper, it is not obvious how to choose a proper source calibration to apply to the CAR data sets. Since the CAR viewed both sources for most calibrations, detailed intercomparisons are required. After careful tracking the history of the calibration data for each source and intercomparison of the two sources via the CAR data, the 2/96 6-foot sphere and 3/96 48-inch hemisphere calibrations were determined to be the most reliable and used for all data after 1994. Therefore, all pre- and post-deployment calibration data for MAST (June 1994), SCAR-C (September 1994), ARMCAS (June 1995), and SCAR-B (August-September 1995) were reprocessed. Using these data, Jason Li has processed the FIRE (flights 1296 - 1303), ASTEX (flights 1557 - 1570), LEADEX (flights 1539-1546), and ARMCAS (flights 1675 - 1684) CAR measurements. Each CAR HDF file has gone through rigorous quality checking. A set of software codes were created to read HDF objects and compare them directly with those in the raw data to ensure CAR HDF processing was bug free. These data are all classified as research grade products and ready for scientific usage (see below).

b. Analysis and Interpretation

The MAS thermal/vacuum chamber data collected at Goddard last November were analyzed by Steve Platnick and Tom Arnold. A set of fitting functions was developed, both for warm and cold tests, that, taken together, can be used to approximate the instrument gain changes for any in-flight temperature and any ground calibration temperature. These fitting functions, together with emissivity corrections, were used by Paul Hubanks to process MAST Level-1B data. Running both new Level-1B and the original data through our cloud retrieval algorithms, Steve Platnick concluded that the latest processing provides more reasonable retrieval results than the initial results obtained without the proper instrument thermal adjustments applied to the calibration coefficients.

Platnick also implemented and integrated the correlated k-distribution method to create a single code. For a given standard atmosphere or MAST sounding, this code calculates the above-cloud atmospheric transmittance and emittance (if appropriate) for MAS channels 2, 7, 10, 20, 23, 31, 32, 44, and 45. This code also does a three-variable fit to the transmittance and emittance in each band as a function of the cosine of the zenith angle. These fits are later used in Platnick's cloud retrieval code for atmospheric corrections. Six days of AVHRR imagery, including in-track and out-of-track data during the MAST experiment, were provided by the Naval Postgraduate School. Results from analyzing MAS and these AVHRR data have been submitted for publication as a journal article.

Both Tom Arnold and Jason Li are performing MAS and AVIRIS radiance intercomparisons. Calibrated radiances from both MAS HDF and AVIRIS data are first extracted and geometrically remapped with additional roll-angle offset corrected for MAS data. This fine roll-angle correction is necessary because MAS is housed in the wing pod whereas AVIRIS is located in a different location on the plane, namely the Q-bay (equipment bay behind the pilot). Next, the AVIRIS spectral data were convolved with the bandpass characteristics of the MAS 25 visible and near-infrared bands. Two of the ARMCAS datasets were selected for the intercomparison (7 and 12 June 1995). These two scenes reveal different characteristics, but offer reasonably good targets over a broad radiance range. Targets selected in the 7 June case were part of a deep convective cloud turret over the Brooks range, dark areas shadowed by the turret, and smaller (warmer) convective cells around the turret. The 12 June data were a clear sky scene over the Yukon River. Selected targets in this case were snow fields, small lakes, and defined land / terrain areas.

Figure 5 shows some preliminary results from MAS bands 2, 6, 7, 9, 10, and 20. These bands have been selected because a number of adjacent bands are similar and thus all bands can be adequately represented by this set. Generally the shorter wavelength bands 1-9 compared better than the longer wavelength bands 10-25 (>1.6 µm). All bands show, at lower radiance, a positive offset of the MAS radiance as compared to AVIRIS. The cause of this offset is unclear and should be further investigated. Notable also is the change in slope that occurs in the transition from bands 8-10. One possible explanation for this slope change is the thermal correction. Additional analysis is required to determine the cause of the differences. Analysis of 1996 MAS-AVIRIS intercomparisons will be useful since the thermal effects have been even further reduced from the 1995 configuration.

Robert Pincus applied the diffusion domain test to all CAR data from three experiments - FIRE, ASTEX, and MAST. He found that a minuscule percentage of CAR scans pass the test, and that almost all of these occur in the FIRE dataset. The droplet size distribution measured at each second is used to compute the asymmetry factor and the similarity parameter, from which the single scattering albedo can be deduced using Mie theory. These computations are compared with the similarity parameter deduced from analysis of CAR radiance measurements.

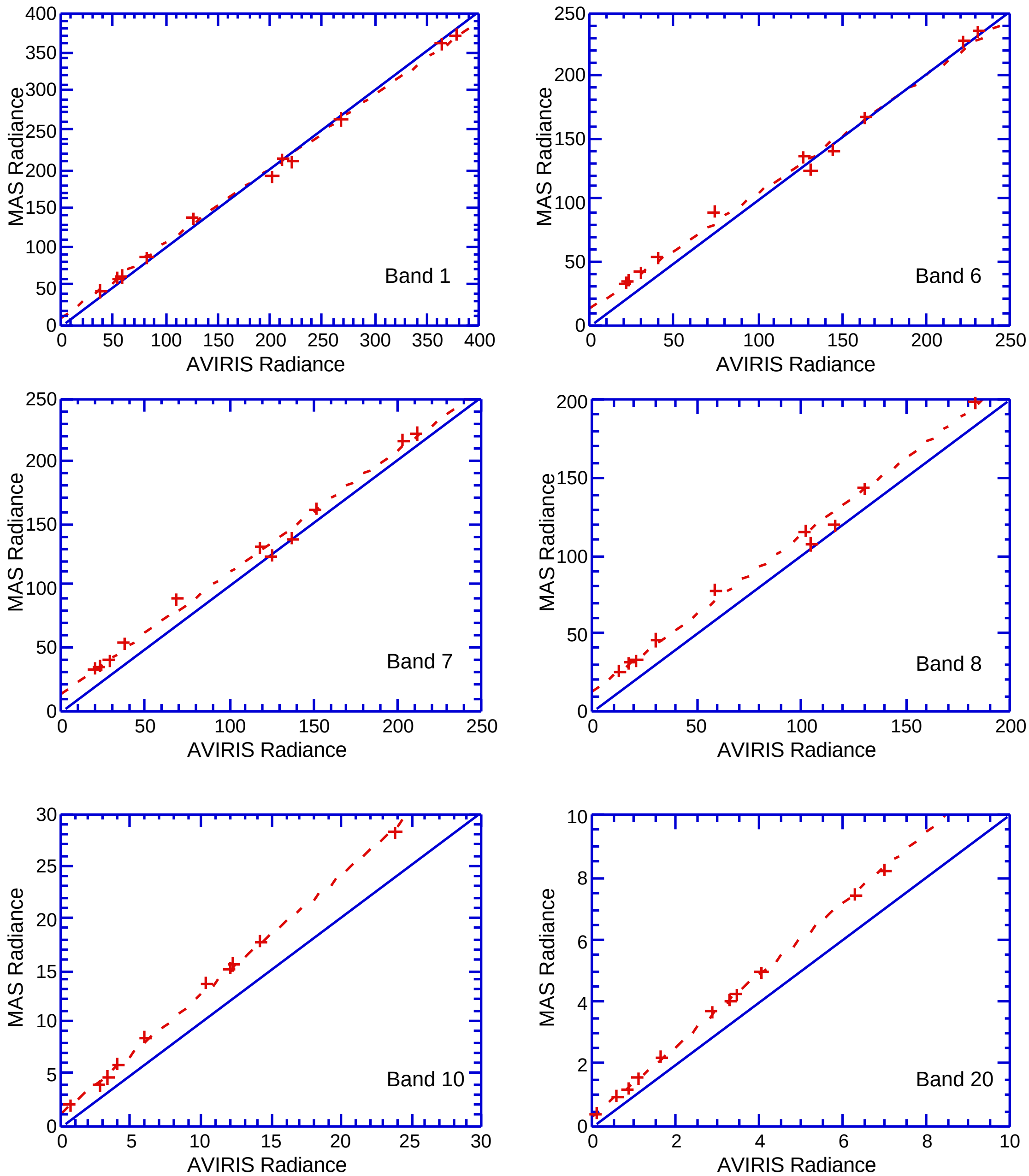

Figure. 5. Selected bands comparing MAS and AVIRIS data. Radiance units are W m^{-2} μm^{-1} sr^{-1}. Dashed lines are linear regression lines of best-fit, solid lines are 'ideal' (1 to 1) comparison.

Figure 6 shows the dependence of similarity parameter in channel 12 (2.2 µm) on effective radius as measured by the in situ cloud microphysics probes. Values computed from droplet spectra are shown as small dots; values derived from CAR measurements are shown as larger dots. Non-parametric best fit lines through each set of data points are also indicated. Note that the effective radius is not a unique predictor of similarity parameter in this instance. The generally

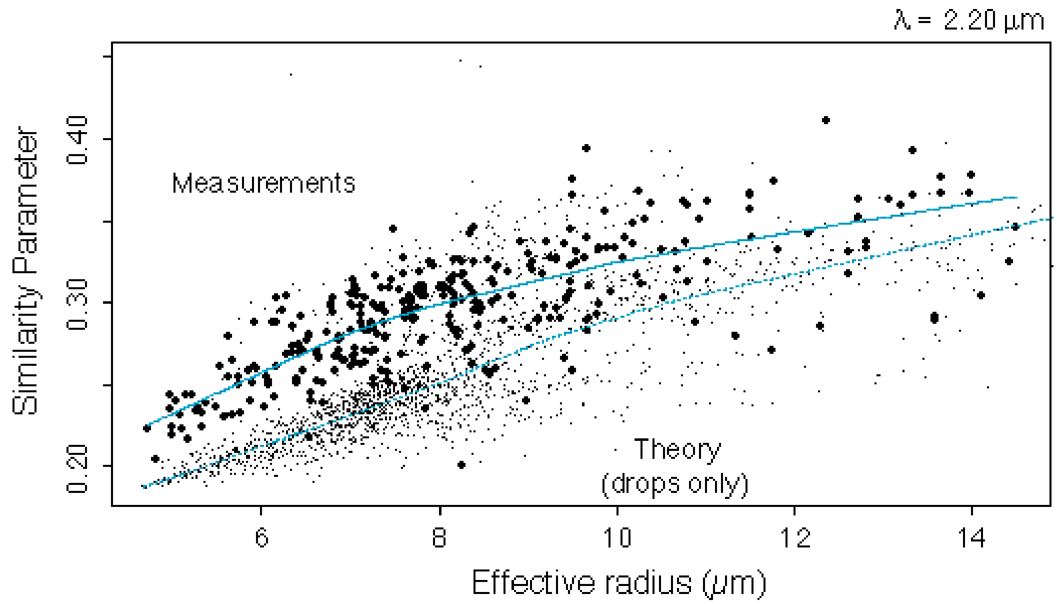

Figure. 6. Similarity parameter as a function of effective radius for data acquired at 2.20 µm in optically thick clouds (FIRE marine stratocumulus experiment).

larger values of similarity parameter measured by the CAR indicate the role of water vapor absorption at this wavelength. We are exploring ways to accurately treat this absorption; in the meantime we note that both the magnitude of the similarity parameter and its dependence on effective radius as observed by the CAR provide experimental evidence that absorption by clouds is reasonably well predicted by current theories. Also note that measurements of the similarity parameter show appreciable variability, with relatively wide ranges in retrieved values for a given effective radius. This variability may be due at least in part to internal inhomogeneity in cloud extinction. More simulations of CAR measurements using both discrete-ordinate (DisORT) and backward Monte Carlo radiative transfer codes are currently underway to investigate cloud properties in the diffusion domain. The primary focus is on evaluating the amount of numerical noise in Monte Carlo computations by computing the radiance field inside a homogeneous cloud. It has been found that the algorithm used to identify the diffusion domain is quite sensitive to the zenith and nadir radiances. To accelerate the investigation, various plotting tools have been created. For example, with the help of Jason Li, the cross-correlation coefficients can be examined in a 4-D space using an IDL shade volume technique.

IV. Anticipated Future Actions

a. Continue to work on MODIS *v1* cloud retrieval algorithm delivery;

b. Continue to work on MODIS ATBD and finalize Science Data Validation Plan for the Atmospheres Group;

c. Continue to analyze MAS, AVIRIS, and CLS data gathered during the ARMCAS campaign, as well as AVHRR, University of Washington C-131A in situ data, and surface data, all with the express purpose of helping to develop the MODIS cloud masking algorithm;

d. Continue to analyze MAS, AVIRIS, and CLS data gathered during the US-Brazil SCAR-B campaign, as well as University of Washington C-131A in situ and radiation data to study aerosol-cloud interactions;

e. Continue to analyze surface bidirectional reflectance measurements obtained by the CAR during the Kuwait Oil Fire, LEADEX, ASTEX, SCAR-A ARMCAS, and SCAR-B experiments, as well as analyze CAR diffusion domain data from MAST and FIRE-87;

f. Start to analyze MAS, HIS, and CLS data gathered during the NASA SUCCESS field experiment in Kansas from 8 April to 10 May 1996;

g. Prepare for and participate in the TARFOX field experiment in NASA Wallops from July 8 to 31, 1996;

h. Attend the Conference on NASA's Earth Observing System, SPIE (4-9 August 1996), in Denver, CO. and the International Radiation Symposium, (19-25 August 1996) in Fairbanks, AK.

V. Problems/Corrective Actions

No problems that we are aware of at this time.

VI. Publications

1. King, M. D., and M. K. Hobish, 1996: Satellite instrumentation and imagery. *Encyclopedia of Climate and Weather,* S. H. Schneider, Ed., Oxford University Press, 652–655.

2. King, M. D., W. P. Menzel, P. S. Grant, J. S. Myers, G. T. Arnold, S. E. Platnick, L. E. Gumley, S. C. Tsay, C. C. Moeller, M. Fitzgerald, K. S. Brown and F. G. Osterwisch, 1996: Airborne scanning spectrometer for remote sensing of cloud, aerosol, water vapor and surface properties. *J. Atmos. Oceanic Technol*., **13**, 777-794.

3. Tsay, S. C., P. M. Gabriel, M. D. King and G. L. Stephens, 1996: Spectral reflectance and atmospheric energetics in cirrus-like clouds. Part II: Applications of a Fourier-Riccati approach to radiative transfer. *J. Atmos. Sci*., in press.

4. Platnick, S., P. A. Durkee, J. P. Taylor, S.-C. Tsay, R. J. Ferek, K. Nielson, M. D. King and P. V. Hobbs, 1996: The role of background cloud microphysics in ship track formation. *J. Atmos. Sci*., submitted.