Quarterly Report
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I. Near-term Objectives

Apply extensively the retrieval algorithm, developed by Nakajima and King for determining the cloud optical thickness and effective radius of clouds from reflected solar radiation measurements, to all calibrated and geolocated ASTEX data gathered by the MAS (MODIS Airborne Simulator). This program has thus far been applied to 2 channels of the MAS (0.665 and 2.142 microns), but will in the future be extended to multiple wavelengths appropriate for MODIS. A reduction of angular information, which were stored in the codes and required by the retrieval algorithm, should be sought in order to increase the capacity of containing multi-spectral information, such as adding the 3.75 micron channel.

II. Task Progress

1. SCAR-A Experiment

During the month of July, Michael King, Si-Chee Tsay and Liam Gumley devoted more than two weeks of their time to the SCAR-A (Sulfates, Clouds And Radiation - America, based in NASA Wallops Flight Facility during July 10 - 28, 1993) deployment. Tom Arnold, Dave Augustine, Da-Sheng Feng, Robbi Harvey and Ward Meyer participated in individual missions. An invited Russian scientist, Dr. Irina Mel'nikova, also visited SCAR-A for about two weeks. Other visiting scientists included several Brazilians with whom we will collaborate in Brazil during SCAR-B.

The main objective of SCAR-A was to study the interactions between clouds and aerosols from ground-based, airborne and spaceborne platforms. Other objectives included: obtaining a comprehensive dataset for validating MODIS algorithms; measuring surface bidirectional reflectance patterns; studying radiative properties of cirrus clouds; and cross-calibrating many instruments used in remote sensing including the Thematic Mapper on Landsat and AVHRR on NOAA operational satellites. The SCAR-A consisted of the NASA ER-2 aircraft carrying the MAS, AVIRIS (Airborne Visible/Infra-Red Imaging Spectrometer) and an RC-10 mapping

camera, and the University of Washington's C-131A research aircraft carrying a wide variety of instrumentation to measure atmospheric dynamics, thermodynamics, microphysics, chemistry and radiation. In addition, a ground-based sunphotometer network was installed supplemented by roving ground stations and light aircraft carrying sunphotometers.

During the entire experiment, 8 research flights were conducted by the ER-2 aircraft, which consumed about 28.5 flight hours, and 8 research flights were conducted by the C-131A, which used about 25.5 hours. Highlights of these flights are as follows:

- Coordinated flights between the ER-2 and C-131A were conducted over the ground sites at Hog Island, Dismal Swamp (Hampton Roads), and Pine Barrens (Coyle Field), consisting of 5 overflights of the ground sites.

- Two of the ER-2 missions were well coordinated with Landsat overpasses and another three missions were well coordinated with AVHRR overpasses. Targets in these five missions ranged from clear sky to widespread cirrus clouds.

- Three of the ER-2 missions performed a mapping grid pattern, consisting of flight legs spaced 24 km apart and parallel, in which there were numerous cumulus clouds penetrating a very hazy boundary layer. The C-131A flew a series of cross sections across the ER-2 ground tracks, penetrating the upper layers of the clouds.

- One of the ER-2 missions traversed an extensive cirrus cloud band, coverage of which included thin and thick cirrus clouds over both land and water, as well as over other multi-layer clouds.

- Two of the C-131A missions measured the surface bidirectional reflectance over ocean, deciduous forests, and coniferous forests at different zenith angles and hazy conditions.

- One of the C-131A missions characterized the sea salt aerosol on-shore and off-shore at various altitudes and under warm frontal conditions.

- In addition, two cloud-free high resolution images of flooding in the US Midwest were acquired on July 29, 1993 by the MAS.

a. MODIS-related Instrumental Research

Prior to the SCAR-A experiment, the MAS was sent for emergency repair to Daedalus for dewar hold-time problems, a failing in coating of the pfund optics assembly, and tests of spectral shift with temperature. The spectral bands of 0.547, 0.664, 0.875, 0.945, 1.880, 2.142, 3.725, 8.563, 11.002, 13.186, and 12.032 microns were selected for channels 2-12 of the MAS for the SCAR-A experiment. Gain settings for channels 2-7 were varied from one mission to another to maximize the information collected for clear, hazy and cloudy conditions.

Generally, the MAS performed very well and collected good quality data in SCAR-A except for port 3, whose dewar hold-time was still limited to around 3.5-4 hours after takeoff. Two in-field calibrations were performed by Tom Arnold, Liam Gumley and Si-Chee Tsay on July 21 (less humid) and July 27 (more humid), using the Goddard 48-inch integrating hemisphere. Analysis of these calibration data was performed by Tom Arnold. Peak count values for each channel of each gain setting were first extracted from the raw data and then, the slope values (counts to radiance conversion values) for each gain setting were produced for each channel. The final slope value, to be used to calibrate the SCAR-A data, is generally determined by choosing the slope value with the highest number of lamps observed without saturation. These calibration data were given to the SDST for processing three SCAR-A MAS data (July 12, 16 and 28). The MAS post-SCAR-A calibrations were performed by Pat Grant at Ames on August 23 and the port 3 dewar hold-time was also repaired at the same time. Pat Grant is in the process of analyzing the MAS post-SCAR-A calibration data, including the temperature sensitivity on port 1 and 2.

The modification work on the CAR (Cloud Absorption Radiometer) was completed on July 8 and in the SCAR-A experiment the spectral bands of 0.470, 0.673, 0.754, 0.867, 1.03, 1.27 and 1.22 microns were selected for the continuously sampling channels (1-7) and 1.55, 1.64, 1.72, 2.10, 2.20 and 2.30 microns for the filter wheel channels (8-13). Preliminary comparisons between the pre-flight calibration and the June 22 calibration (with the old optics and new InSb detector), both using the 48-inch hemisphere and the six-foot sphere, were obtained by Tom Arnold. Results looked encouraging.

During the first few flights of SCAR-A, the performance of the CAR filter wheel channels (8-13, new InSb detector and many new optics) was not very constant and seemed to deteriorate with each flight. The new near-IR detector took about 30 minutes or more to reach its cooled operating

temperature of 77 K. In the lab, the detector reached its operating temperature within 15 minutes, quite consistently. One cause for this increase in cool-down time on the aircraft may have been the high ambient temperature outside, which on several days reached 100 F. Thus, the CAR was returned to GSFC by Ward Meyer on July 20 for a one-day fix-up. Max Strange solved numerous problems the next day. He fixed the door motor so that it would turn off automatically, once the door was completely open or closed. He also analyzed the unreliable performance of the near-IR detector and analyzed the cause of the variable dc-restore level, and fixed the latter problem by replacing a faulty timer circuit with new components. Then, the CAR was again shipped back to Wallops and in general it performed well through the last flight of SCAR-A.

The pre- and post-SCAR-A calibration of CAR was conducted by Tom Arnold and Nita Walsh, using both the 48-inch hemisphere and the six-foot sphere on July 6 - 7 and August 11 - 12, respectively. A few problems were encountered in processing these calibration data by Tom Arnold. Most of them were due to averaging and/or sampling problems with the calibrator. Otherwise, preliminary analysis of the post-SCAR-A calibration data appear reasonably good in comparison with the pre-SCAR-A calibration data. These calibrations must be further analyzed to determine how they will be used to determine the final calibration coefficients for the SCAR-A data.

b. MODIS-related Data Processing and Algorithm Study

The MODIS Algorithm Theoretical Basis Document (ATBD) was completed by Michael King and Si-Chee Tsay and delivered to SDST on time. The title of this ATBD is the "Theoretical Basis of Cloud Retrieval Algorithms for MODIS: Cloud Cover, Thermodynamic Phase, Optical Thickness and Effective Particle Radius." Equations for the ASTEX MAS calibration were re-analyzed by Tom Arnold one final time to ensure accuracy and the final calibration report was in the review process. The report for FIRE-II Cirrus IFO calibration was also completed by Tom Arnold. After careful review, several changes and additions were made, including reanalyzing the temperature correction for channels 3-6. A best-fit exponential curve fit was added to define the change in the MAS counts as a function of temperature for each of the affected channels.

The MAS data from the FIRE flight on December 5, 1991 were re-calibrated by Liam Gumley using the temperature sensitivity correction algorithm developed by Tom Arnold. These data were then compared to the AVIRIS data obtained over corresponding targets. The new calibration

was found to reduce the temperature sensitivity effect in the 1.617 micron channel. The final calibration (without temperature sensitivity correction) for the 0.681 micron channel also improved the match with AVIRIS. This final version of the MAS FIRE calibration will be used by the MODIS SDST to produce MAS Level-1B output data.

Liam Gumley generated 3-channel RGB composite imagery from the MAS data, by utilizing the software packages of Transform (for selecting regions of interest), IDL (for producing RGB TIFF images), clrpaint (for adding labeling), and xv (for converting to GIF for distribution and SGI RGB format for printing) available on "redback" and "climate" computers. Printing of the imagery was done by using a Kodak XL-7700 thermal dye transfer printer. To produce geometrically corrected images, a resample scheme to obtain the same pixel spacing along track and across track (to account for geometric distortion and varying ER-2 ground speed) was also developed by Liam Gumley. Currently all RGB images have been remapped to an ER-2 altitude above the image surface of 20 km. This yields 582 (out of 716) pixels across track and 64 meter pixel spacing both along track and across track. Mapping the image data to a specific altitude (e.g., cloud deck) is also possible, however yielding a smaller number of pixels across track. To this point, the CLS (Cloud Lidar System) attenuated backscatter data will be very helpful in determining an appropriate MAS remapping altitude.

Three SCAR-A MAS data flights have been accessed to generate remapped RGB composite images. The scenes imaged thus far include: (1) the Great Dismal Swamp (NC), Hog Island (VA, an LTER ground site) and Pine Barrens (NJ) on July 16, (2) New York City on July 18, and (3) the Great Dismal Swamp on July 28. A striking feature observed on July 28 is a strong backscattering in the anti-solar direction in the principal plane that did not appear in the July 16 case. More theoretical studies are needed. In addition, three RGB composite images over the flooded Mississippi and Missouri Rivers areas (St. Louis, Kansas City, and western Missouri near Lexington, on July 29) were produced and transferred to the Code 913 Internet anonymous FTP site ("climate"). Within three days, a total of 445 downloads had been performed on these images (around 220 each for the Kansas City and St. Louis scenes placed on "climate").

Cloud Lidar System (CLS) data for one of the FIRE-II Cirrus cases (December 5, 1991), provided by Bill Hart and Jim Spinhirne, have been decoded and displayed as images on "redback" by Liam Gumley. These data were attenuated backscatter, and did not have clear atmospheric scattering removed and are somewhat noisy. The least noisy one is the channel 3 at 1.064 micron (unpolarized). These data were interpolated to

the same along track resolution as the MAS and compared to remapped MAS 3 channel RGB composite (10.95, 1.93, 0.66 microns) cloud imagery. The main feature noticed is that the lidar detects backscatter at 11-13 kilometers regardless of whether clouds are observed in the MAS data. The CLS seems to detect very thin clouds that the MAS does not easily see them. Other CLS attenuated backscatter data for ASTEX June 17 case were also obtained from Bill Hart, and decoded and displayed next to the corresponding MAS RGB image. This method of displaying imagery holds promise for various cloud sensing validation studies.

Dave Augustine and Ward Meyer have processed all CAR active scan data (from flights 1445-1485 of Alaska, 1990 to flights 1605-1612 of SCAR-A) and also completed the conversion of the IBM version of the Active Scan code to a version that is portable but primarily running on the Macintosh. Da-Sheng Feng, now off-site at the University of Arizona, has remotely analyzed part of the CAR diffusion domain data and performed the sensitivity studies of varying diffusion domain criteria. In previous analyses by King, the criterion for deterimining a CAR scan being within the diffusion domain was set to a 2.5% standard deviation from the theoretical (cosine) function. In the current studies, various levels of 2.25%, 2.0%, 1.75%, ..., 0.50% and 0.375% were selected to see how diffusion domain data points vary with these descending criteria, as well as how cloud single scattering albedos, effective droplet radii, total droplet surface areas and scaled optical depths are associated with these data points.

Preliminary results show that when the criteria is lowered to 0.5% level, the deep dips, which are the common and outstanding features at the 2.5% level, disappeared. At the 0.5% level, the degree of scattering points in measured single-scattering albedos are much smaller than in the cases at the 2.5% level. All data points of the 0.5% level are associated with larger scaled optical depth, which in turn were the products of ship tracks. Can we consider that these scans were well in the diffusion domain? Or without the modification of ship tracks, were there sufficient scans in the diffusion domain? As such, many sections of the clouds in Flight 1301 might not be fully qualified as clouds in the diffusion domain, although we don't have a deterministic diagnostic criterion for the diffusion domain thus far. More case studies are needed to address these questions.

c. MODIS-related Services

Meetings:

1. Michael King attended the EOS/Social Sciences Workshop at Goddard Space Flight Center, MD on July 29-30;

2. Si-Chee Tsay attended the CEPEX workshop at Scripps Institution of Oceanography, La Jolla, CA on August 10-12;

3. Michael King, Si-Chee Tsay and Liam Gumley attended the CERES Cloud Working Group meeting at Denver, CO on September 20-22;

4. Michael King and Si-Chee Tsay attended the ONR WESTEX workshop at the Naval Postgraduate School, Monterery, CA on September 22-24;

5. Michael King, Si-Chee Tsay, Steve Platnick and Liam Gumley attended the MODIS Science Team Meeting at Goddard Space Flight Center, MD on September 29 to October 1.

Seminars:

1. Si-Chee Tsay was invited to give a MAS-related seminar entitled "Measurements of Cloud Radiative Properties and Cloud Retrieval Algorithm" at Scripps Institution of Oceanography, La Jolla, CA on September 24.

III. Anticipated Activities During the Next Quarter

a. apply extensively the MODIS Cloud Retrieval algorithm through all calibrated and geolocated ASTEX data gathered by the MAS;

b. compare retrieved cloud parameters from the 3.75 micron channel with those obtained from the usual 0.665 and 2.142 micron channels;

c. conduct sensitivity studies on the capability of: reducing angular information, increasing multi-spectral information, and addressing spectral band characteristics;

d. continue the effort of refining the data analysis algorithm and re-examine more carefully the retrieval of cloud optical and microphysical properties by using data gathered from MAS;

e. continue to analyze the bidirectional reflectance measurements obtained during the Kuwait Oil Fire, LEADEX, ASTEX and SCAR-A experiments;

f. start to analyze data sets obtained from the TOGA/COARE and CEPEX field campaigns.

IV. Problems/Corrective Actions

No problems that we are aware of at this time.

V. Publications

One Abstract was submitted to the AGU Fall meeting (San Francisco, December 6-10, 1993) and five abstracts were submitted to the AMS Eighth Conference on Atmospheric Radiation (Nashville, January 23-28, 1994):

1. King, M. D., 1993: Earth Observing System (EOS) Status and Overview. To be presented at AGU Fall Meeting, San Francisco, CA (invited).

2. King, M. D., and S. C. Tsay, 1994: Radiative and microphysical characteristics of a multi-layered cloud system: Preliminary results from TOGA COARE. To be presented at the 8th Conference on Atmospheric Radiation, American Meteorological Society, Nashville, TN (section 4: radiation instrumentation and field experiments).

3. Tsay, S. C., P. M. Gabriel, M. D. King and G. L. Stephens, 1994: A Fourier-Riccati approach to radiative transfer. Part II: Computations of spectral reflectance and heating rates in cirrus-like clouds. To be presented at the 8th Conference on Atmospheric Radiation, American Meteorological Society, Nashville, TN (section 5: radiative transfer theory).

4. Tsay, S. C., and M. D. King, 1994: Remote sensing and retrieval of surface bidirectional reflectance. To be presented at the 8th Conference on Atmospheric Radiation, American Meteorological Society, Nashville, TN (section 6: radiative properties of the atmosphere, clouds, aerosols, and surface).

5. Gumley, L. E., M. D. King and S. C. Tsay, 1994: Multi-sensor remote observations of thin cirrus clouds during FIRE Cirrus II. To be presented at the 8th Conference on Atmospheric Radiation, American Meteorological Society, Nashville, TN (section 4: radiation instrumentation and field experiments).

6. King, M. D., 1994: The application of EOS to studies of atmospheric radiation and climate. To be presented at the AMS Annual Meeting, Nashville, TN (invited).

7. King, M. D., and M. K Hobish, 1994: Satellite instrumentation and imagery. Encyclopedia of Climate and Weather (in press).