Semi-Annual Report
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I. Task Objectives

The Moderate Resolution Imaging Spectroradiometer (MODIS) being developed for the Earth Observing System (EOS) is well suited to the global monitoring of atmospheric properties from space. Among the atmospheric properties to be examined using MODIS observations, clouds are especially important, since they are a strong modulator of the shortwave and longwave components of the earth's radiation budget. A knowledge of cloud properties (such as cloud cover, cloud thermodynamic phase, optical thickness, and effective particle radius) and their variation in space and time, which are our task objectives, is also crucial to studies of global climate change. In addition, with the use of related airborne instrumentation, such as the Cloud Absorption Radiometer (CAR) and MODIS Airborne Simulator (MAS) in intensive field experiments (both national and international campaigns, see below), various types of surface and cloud properties can be derived from the measured bidirectional reflectance. These missions have provided valuable experimental data to determine the capability of narrow bandpass channels in examining the Earth's atmosphere and to aid in defining algorithms and building an understanding of the ability of MODIS to remotely sense atmospheric conditions for assessing global change. Therefore, the primary task objective is to extend and expand our algorithm for retrieving the optical thickness and effective radius of clouds from radiation measurements to be obtained from 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*

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 "Theoretical Basis of Cloud Retrieval Algorithms for MODIS: Cloud Cover, Thermodynamic Phase, Optical Thickness and Effective Particle Radius." Currently, this ATBD is undergoing a revision to include comprehensive error analyses and spectral utilization, performed by Dr. Steve Platnick, a new member of this group. To better describe the activities of our algorithm study, we separate our tasks and manpower as follows.

(1) Retrieval of cloud optical thickness and effective particle radius for plane-parallel like water clouds. This is one of our core research tasks for MODIS. Figure 1 shows flow chart of this algorithm. Generally, cloud retrieval code for optical thickness and effective particle radius consists of roughly three parts: (i) determination of Mie optical parameters from a suitable integration over drop size distribution, and in general, channel spectral response and solar irradiance; (ii) calculation of a library (or many lookup tables) of bidirectional reflectance and effective emittances for a plane-parallel geometry; and (iii) a scheme for determining the best match between measured data and entries in the library. Steve Platnick, Dr. Menghua Wang (another new member of this group), Si-Chee Tsay and Michael King are the major scientists working on this task.

(2) Cirrus cloud contamination and thermodynamic phase discrimination. One of the most difficult problems in the retrieval algorithms is the existence of multi-layer cloud systems, such as thin cirrus clouds overlying boundary layer strati-form clouds. Since the spatial distributions of cirrus clouds are highly inhomogeneous, it is very difficult to set a particular measured reflectance as the threshold value. Multi-dimensional radiation model and ice crystal optical model are needed to explore this relationship. In addition, the difference and/or ratios of the reflected solar radiation in the 0.645, 1.64, and 2.13 µm channels contain information regarding cloud particle thermodynamic phase, due to the distinct difference in bulk absorption between water and ice at these wavelengths. The MAS measurements, together with model simulations, will be useful for this task investigation. Si-Chee Tsay and Liam Gumley are the major scientists working on this task.

(3) Cloud masking algorithm development. Cloud masking is an essential step in producing many MODIS products, since cloud retrieval schemes, as well as all other atmosphere, ocean and land analyses, follow the identification of the nature of the scene within the pixel (cloud, shadow, clear sky, ocean, etc.). The development of a cloud mask using MODIS data is being pursued in cooperation with Paul Menzel, John Barker and Michael King from MODIS and Bryan Baum and Ron Welch from CERES. For the past few years, we have collected many valuable MAS multispectral data under both clear sky and cloudy conditions. This forms a good test-bed for examining any existing cloud masking algorithms and may provide an opportunity to develop a proper algorithm for our own purpose. Liam Gumley and Steve Platnick are the principal scientists working on this task.

(4) Surface bidirectional reflectance. Surface radiative properties are needed in any cloud retrieval algorithms. During the past several years, many angular distributions of natural surface reflectance have been obtained systematically by the CAR onboard the University of Washington's C-131A research aircraft (e.g., Kuwait oil fire smoke, snow over tundra, sea ice, vegetation, and ocean). These data sets form a base for analysis and model simulation to simplify various types of surface characteristics. Si-Chee Tsay, Ward Meyer and Michael King are the principal participants working on this task.

(,5) MAS calibration and visualization support. Accurate calibration is the first step to quantitatively utilize atmospheric radiation data. Calibration of MAS visible and near-IR channels is obtained by transferring the calibration of an integrating sphere to the MAS channels. Since there are no on-board heaters or pressurizing device, laboratory (or field) conditions do not mimic the cold operating temperatures of the MAS (–20° to –40° C) and the low pressures (-50 mb) at the ER-2 operating altitude. The use of a cold vacuum chamber is needed to properly determine each channel gain versus temperature variation. Once these relationships have been determined for each spectral charnel, room temperature calibrations can then be used to determine proper calibration constants at the MAS operating temperatures. Another complication added in the calibration is the involvement of molecular absorption, since the total path distribution of the absorbing gas is not well defined (see below for more details). Tom Arnold and Steve Platnick are the major contributors working on this task. Real-time display for a vast volume of MAS data (e.g., 50 channels) is an important but difficult task during field deployments. Dave Augustine is the major contributor working on developing a new MAS visualization program (see below for more details).

b. *MODIS-related Instrumental Research*

Prior to the SCAR-A (Sulfates, Clouds And Radiation - America) experiment, based at NASA Wallops Flight Facility during July 10-28, 1993, the MAS was sent for emergency repair to Daedalus for dewar hold-time problems, a failing in the coating of the pfund optics assembly, and tests of spectral shift with temperature. The spectral bands at 0.547, 0.664, 0.875, 0.945, 1.880, 2.142,3.725, 8.563, 11.002, 13.186, and 12.032 µm were selected for charnels 2-12 of the MAS for the SCAR-A experiment. Gain settings for charnels 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 during 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. The MAS post-SCAR-A calibrations were performed by Pat Grant at Ames on August 23 and a repair of the port 3 dewar hold-time was attempted at that same time. Analyses of these calibration data were completed by Tom Arnold, including the temperature sensitivity of ports 1 and 2. More discussions of the SCAR-A calibration are given in the following section. These calibration data, including a final report, will be given to SDST for processing of SCAR-A MAS data.

A Videoconference was held between GSFC and Ames on December 22 to discuss several matters relating to MAS performance. The topics were:

- MAS 50-channel data system, and field quicklook system;
- MAS dewar problems; and

- MAS visible / near-IR calibration in molecular absorption bands.

Ames reported that a final strategy for recording the data in-flight has not been decided. The recording media will be Exabyte 8500 tapes, but it has not been decided whether to use two tapes sequentially or to interleave the data on two tapes (higher transfer rate). GSFC expressed a preference for using two tapes sequentially. The data format has also not been finalized. Various packing strategies were discussed. No date was given for a release of the data format specification. GSFC will need to provide input to Ames on the requirements for the data format as well as input on how often and from what source time and geolocation data are required. Then, GSFC reported on progress made on a prototype MAS quicklook system, designed by Dave Augustine in IDL on an SGI workstation. Ames agreed that GSFC take the lead in the software development, and that Ames would provide the necessary workstation hardware and IDL license. GSFC will need to interact with Ames on the hardware requirements.

Pat Grant recommended that the port 2 and port 3 dewars be replaced at the same time in order to regain the full hold-time for port 3 and to increase the temperature sensitivity of port 2. Due to the short time available for the videoconference, the calibration strategies for the MAS near-IR channels with significant molecular absorption were not fully discussed. For these channels, calibrations using the integrating sphere need to account for the total path distribution taken by photons exiting the sphere. As an example, Steve Platnick used an atmospheric transmittance code (TransM, modified from MODTRAN by Si-Chee Tsay) to perform calculations for the 1.38 µm channel. He showed that the transmittance along a 1 m path is 0.95; 0.76 for a 10 m path, and 0.32 for a 100 m path (calculations were made with a specific humidity equivalent to a relative humidity of 50% at room temperature). With a sphere having a diameter of about 1 m, the mean path of exiting photons must be much greater than this diameter if the sphere is to emit a Lambertian intensity. Such strong absorption presents a difficult problem when calibration accuracy is desired to be on the order of a few percent. A couple of approaches were recommended to gain experience. One is to calibrate the MAS and the sphere at the same time in an environment having no significant short-term changes in atmospheric conditions. This is probably not impossible in most field campaigns. A second approach is to calibrate the MAS at several concentration levels of the absorber (e.g., specific humidities) and determine an empirical fit for the absorbing channels. More studies are needed.

The modification work on the CAR was completed on July 8 during the SCAR-A experiment. The spectral bands at 0.470, 0.673, 0.754, 0.867, 1.03, 1.27 and 1.22 µm were selected for the continuously sampling channels (l-7) and 1.55, 1.64, 1.72, 2.10, 2.20 and 2.30 µm for the filter wheel channels (8-13). 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 de-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 the 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. Analyses between these four calibration data (pre- and post-flight for both 48-inch hemisphere and the six-foot sphere) showed reasonably good agreement. During the analysis of the Great Dismal Swamp data, Si-Chee Tsay and Ward Meyer discovered that there were two types of anomalous scan data requiring careful consideration. One anomaly in a particular scan is caused by the manual gain switch activated in the middle of a CAR scan. This is now more noticeable since the switch is used much more frequently. Another problem is the proper setting of the gain sensitivity in a particular channel with respect to others. Occasionally, small negative intensities are observed for a particular channel when the CAR views a dark target.

C. *MODIS-related Services*

1. MODIS-related experiment: SCAR-A

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 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 may 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: (i) obtaining a comprehensive dataset for validating MODIS algorithms; (ii) measuring surface bidirectional reflectance patterns; (iii) studying radiative properties of cirrus clouds; and (iv) 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 Infrared 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 flew about 28.5 flight hours, and 8 research flights were conducted by the C-131A, which flew about 25.5 hours. Highlights of these flights are as follows:

- Coordinated flights between the ER-2 and C-131A were conducted over 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 in transit from Wallops Island to Topeka.

2. *Meetings*

1. Michael King attended the EOS Social Sciences Workshop at Goddard Space Flight Center 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 in Denver on September 20-22;

4. Michael King and Si-Chee Tsay attended the ONR WESTEX workshop at the Naval Postgraduate School, Monterey 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 on September 29 to October 1;

6. Michael King attended the EOS Payload Advisory Panel meeting, held in Herndon, VA on October 4-6;

7. Si-Chee Tsay attended the Fourth annual JPL airborne geoscience workshop, held in Washington, DC on October 25-26;

8. Michael King attended the Science Working Group for the AM Platform (SWAMP) meeting at Goddard Space Flight Center on November 4-5;

9. Michael King attended the First International MIMR Science Advisory Group meeting, held at the European Space Research and Technology Centre (ESTEC), Noordwijk, Holland, November 16-18.

3. *Seminars*

1. Michael King gave the luncheon address at the AIAA luncheon in New Carrolton, MD on September 16, entitled “Earth Observing System (EOS)-Science Objectives and Challenges;”

2. Si-Chee Tsay gave a seminar entitled “Measurements of Cloud Radiative Properties and Cloud Retrieval Algorithm” at the California Space Institute, Scripps Institution of Oceanography, La Jolla, CA, on September 24;

3. Si-Chee Tsay gave a seminar entitled “Remote Sensing and Retrieval of Cloud and Surface Properties“ in the Department of Meteorology, University of Maryland, College Park, on October 19;

4. Si-Chee Tsay gave a seminar entitled “Remote Sensing Measurements and Modeling Studies of Cirrus Clouds” in the Department of Meteorology, University of Utah, Salt Lake City, on December 1;

5. Michael King gave a presentation on the “Earth Observing System (EOS) Status and Overview” at the AGU Fall Meeting, San Francisco, December 6-10;

6. Michael King gave a seminar entitled “Earth Observing System (EOS)-

Objectives and Challenges" at the University of Maryland, College Park, on November 23.

111. Data / Analysis / Interpretation

a. Data Processing

The analyses and final reports for the FIRE-II Cirrus IFO (1991) and the ASTEX (1992) MAS calibrations were completed by Tom Arnold. These two reports are in the process of being published as NASA Technical Memoranda (see section VI). A similar document for the SCAR-A experiment is nearly ready for review. All Rustrak data, representing the instrument temperature of the MAS as a function of time during a flight of the NASA ER-2 aircraft, and the cold chamber data obtained from Pat Grant (Ames Research Center), were retrieved and analyzed. Figure 2a shows the Rustrak temperature data for five flights during the SCAR-A deployment. Note that temperature curves were displayed only from 30 minutes following takeoff, which is typically required for the ER-2 to get to cruise altitude. The temperature in the first 30 minutes is most strongly influenced by the takeoff temperature which can be quite variable. Once the ER-2 reaches cruising altitude the temperature is much less variable day to day. Based on our previous MAS cold chamber tests, two near-IR charnels (1.83 and 2.14 µm) of SCAR-A are expected to show a temperature sensitivity. The ratio values, using measurements taken at laboratory (+25°C) conditions as references, for these two channels are graphically depicted in Figure 2b. This shows a calibration change with instrument temperature for the 1.83 and 2.14 µm channels of up to about 15% to 25%, respectively. Equations to characterize the change in MAS calibration with temperature for each temperature sensitive channel were derived. Note that some caution is necessary in the use of these equations, since flight conditions are only partially simulated in the chamber tests. Cooling rates of any temperature sensitive parts might be quite different in the chamber as compared to those in the aircraft pod. Also in the chamber the pressure is not reduced and therefore no effects due to the low pressure can be simulated. More testing in a thermal vacuum chamber would be helpful to determine more accurately the calibration change as a function of temperature for future deployments.

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 1.617µm channel. The final calibration (without temperature sensitivity correction) for the 0.681 µm 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-lB 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 m 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.

All ASTEX CAR calibration data, two post-flight (hemisphere and sphere) and one in-field calibration, were analyzed by Tom Arnold. Work on SCAR-A calibration was also completed. After reviewing the 4 calibrations (pre- and post-flight sphere and hemisphere), an average of the pre- and post-flight hemisphere data was chosen as the final CAR calibration for SCAR-A, due to the stability and the more recently measured hemisphere calibration. 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 mainframe version of the Active Scan code to a version that is portable but primarily running on the Macintosh.

b. Analysis and Interpretation

The FIRE-II Cirrus cases (December 5, 1991) were studied extensively to establish an accurate detection of cirrus clouds, to distinguish the thermodynamic phase of clouds, and to test and guide the development of an operational cloud masking algorithm. Figure 3, prepared by Liam Gumley, shows complex structure of cirrus clouds over ocean and land in RGB (remapped MAS 2.14, 1.93, and 0.68 µm, respectively) composite imagery (left) and a vertical profile (1.064 µm attenuated backscatter of the Cloud Lidar System, provided by Bill Hart and Jim Spinhirne) at the nadir direction (right). The main feature noticed is that cirrus clouds (emphasized by the green) were all over the imagery, but their intensity varied with the background information, such as a stretch in color scheme or spectral selection (i.e., using 11 µm to represent land feature instead of 2.14 µm). The cloud message delivered thus far is qualitative. The Cloud Lidar System seems to detect very thin cirrus clouds located at about 11-13 km that the MAS does not easily see. Added to the picture is the highly spatial inhomogeneity. A 2-D radiation model was used by Si-Chee Tsay to examine this spatial inhomogeneity effect on the 1.38 µm (similar spectral characteristics to that of 1.93 pm) reflectance. Results will be presented at the AMS meeting in Nashville 23-28 January 1994.

Figure 4, prepared by Liam Gumley, demonstrated a multi-layered cloud system over ocean, including convective clouds, cirrus clouds, cloud shadows over extensive low-level water cloud deck. This is a good case for distinguishing the thermodynamic phase of clouds and to test existing cloud masking algorithms. MAS imagery data from the 0.68, 1.62, 8.8, 10.95, and 11.95 µm charnels was extracted and converted to reflection function or brightness temperature. Currently, Liam Gumley is studying cloud information provided by the ratio of 1.62/0.68 µm reflection functions, as well as the brightness temperature differences between 8.8 and 11 pm, and 11 and 12 µm. Analysis of these data will be presented by Liam Gumley at the AMS meeting in Nashville January 23-28,1994.

In addition to detection of cloud properties, the MAS is also well suited to the monitoring of surface properties from space. Figure 5 shows three RGB (2.14, 0.994, 0.66 µm respectively) composite images over the flooded Mississippi and Missouri Rivers near St. Louis on July 29. In addition to this image, images were produced for Kansas City and western Missouri near Lexington. The Saint Louis and Kansas City images 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). Liam Gumley is working on a multispectral algorithm for discriminating water from land and applying it to MAS (flood) and Landsat TM (non-flood) data to estimate the extent of the flooding around St. Louis. This paper is in preparation for submission to the *International Journal of Remote Sensing* and will also examine the possibilities for flood monitoring with MODIS.

Surface spectral reflectance is a major parameter of interest to the remote sensing, biospheric sciences, and global change communities. Detailed measurements of the bidirectional reflectance properties of natural surfaces are crucial to understanding and modeling their physical and radiative properties, as well as to aid in the remote sensing of aerosols and clouds above natural surfaces. Figure 6 shows a MAS remapped RGB (2.14, 0.94, 0.66 pm) composite image for the Great Dismal Swamp on July 28. The Great Dismal Swamp area is the green region surrounding the lake at the lower left of the image (Lake Drummond). This area is characterized by quite uniform vegetation cover. Striking features observed on this imagery are the strong backscattering (or the so-called hot spot/opposition effect) occurring in a narrow region of the anti-solar direction in the principal plane and the strong specular reflection (sun glint) by the water surface in a broader region of the solar direction. The solar zenith angle q_0=31.40 and azimuth position of the sun f_0=116. 1°.

Approximately one hour later, the University of Washington's C-131A aircraft flew over the Great Dismal Swamp, with the CAR measuring the full bidirectional reflectance of the scene. Figure 7 shows CAR bidirectional reflection functions for four spectral channels (0.47, 0.87, 1.64, and 2.21 pm). The strong backscattering feature (hot spot) in the anti-solar direction in the principal plane is clearly seen in three of the four channels, with the exception being the 0.47 µm band in which green vegetation has strong absorption. Figure 8 shows the detailed structure of the reflection function measured in the principal plane, including CAR data for two different times (1315Z and 1615Z) and MAS data for one time (1512 Z). Analysis of these data, together with previous bidirectional reflectance data for sea ice and snow over tundra, will be presented by Si-Chee Tsay at the AMS meeting in Nashville January 23-28, 1994. More theoretical studies will be conducted in the future.

IV. Anticipated Future Actions

a. complete work on documentation, standardization, refinement, and integration of our cloud retrieval codes to SDST;

b. complete data analyses of FIRE-II Cirrus observations gathered by the MAS, CLS, and HIS, as well as theoretical studies, and prepare manuscripts for *J. Atmos. Sci.* special issue due in March 1994;

c. apply extensively the MODIS cloud retrieval algorithm through all calibrated and geolocated ASTEX data gathered by the MAS, and prepare manuscripts for *J. Atmos. Sci.* special issue due in May 1994;

d. compare retrieved cloud parameters from the 3.75 µm charnel with those obtained from the usual 0.665 and 2.142 µm channels, and look into the spectral signature of vertical profile in effective particle radius;

e. continue the effort of refining our cloud retrieval algorithm and re-examine more carefully the retrieval of cloud optical and microphysical properties by using data gathered from MAS with in situ data obtained from Hermann Gerber’s PVM probe;

f. complete the development of a quick-look system for the 50-channel MAS for use in the field and develop methods to conduct calibrations of MAS near-IR absorption charnels;

g. participate in the West Coast Ship Track Experiment (WESTEX), taking place June 1-30 from Monterey (C-131A) and Ames Research Center (ER-2), and the follow-up data analysis;

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

i. start to analyze data sets obtained from the TOGA/COARE and CEPEX field campaigns and compare with co-located Landsat data.

V. Problems/Corrective Actions

No problems that we are aware of at this time.

VI. Publications

1. King, M. D., and M. K. Hobish, 1994: Satellite instrumentation and imagery. *Encyclopedia of Climate and Weather,* Robert Ubell Assoc. (in press).

2. Price, R. D., M. D. King, J. T. Dalton, K. S. Pedelty, P. E. Ardanuy and M. K. Hobish, 1994: Earth science data for all: EOS and the EOS Data and Information System. *Photogramm. Eng. Remote Sens.* (in press).

3. Arnold, G. T., M. Fitzgerald, and M. D. King, 1994: MODIS airborne simulator visible and near-infrared calibration: 1992 ASTEX field experiment. *NASA Technical Memorandum* (in press).

4. Arnold, G. T., M. Fitzgerald, and M. D. King, 1994: MODIS airborne simulator visible and near-infrared calibration: 1991 FIRE-Cirrus field experiment. *NASA Technical Memorandum* (in press).

5. 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. Presented at the *8th Conference on Atmospheric Radiation,* American Meteorological Society, Nashville, TN.

6. Tsay, S. C., and M. D. King, 1994: Remote sensing and retrieval of surface bidirectional reflectance. Presented at the *8th Conference on Atmospheric Radiation,* American Meteorological Society, Nashville, TN.

7. Gumley, L. E., M. D. King and S. C. Tsay, 1994: Multi-sensor remote observations of thin cirrus clouds during FIRE Cirrus II. Presented at the *8th Conference on Atmospheric Radiation,* American Meteorological Society, Nashville, TN.

8. King, M. D., 1994: The application of EOS to studies of atmospheric radiation and climate. Presented at the *AMS Annual Meeting,* Nashville, TN (invited).

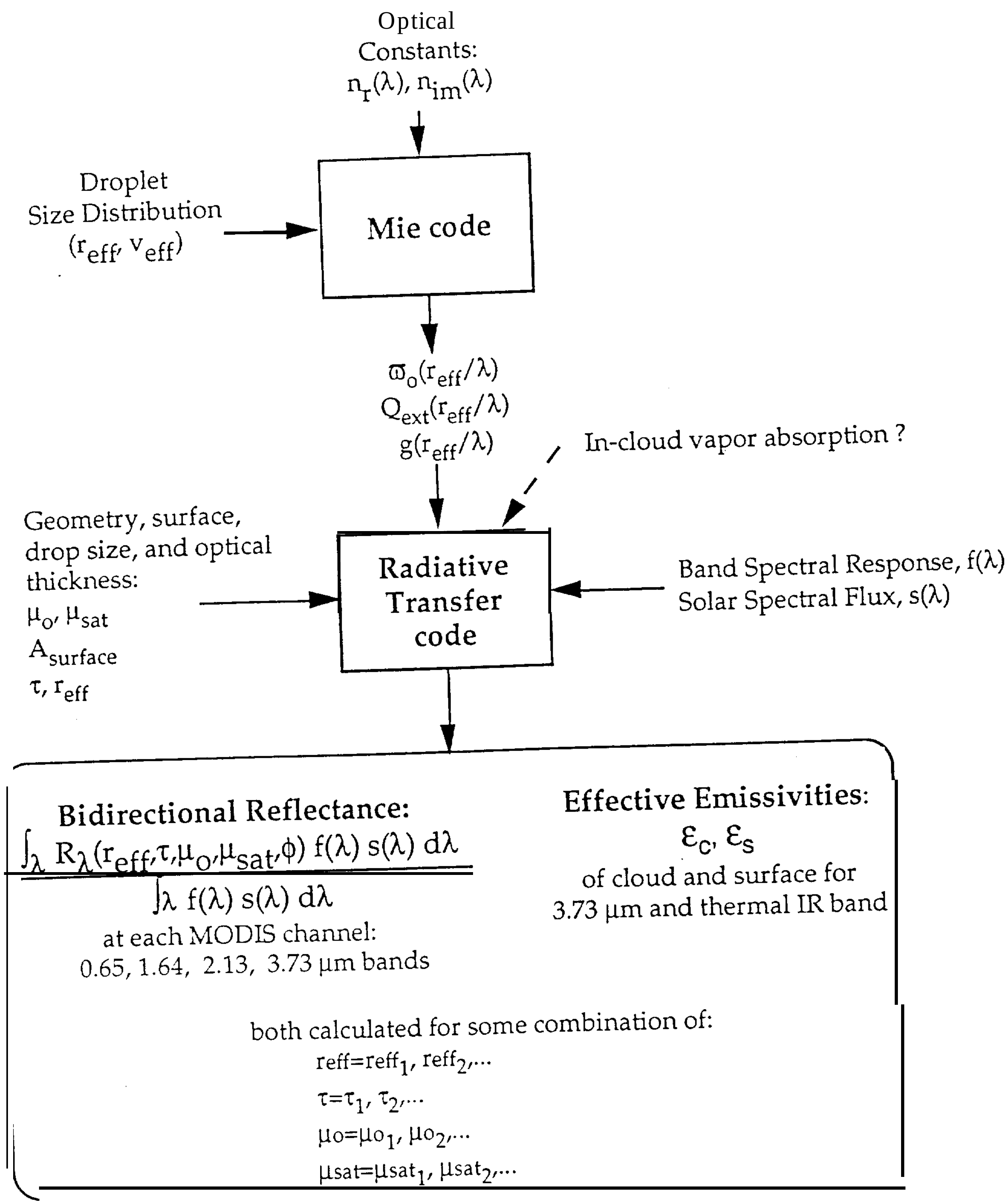


Figure 1a. Schematic for generation of a bidirectional reflectance and effective emissivity library (or lookup tables).

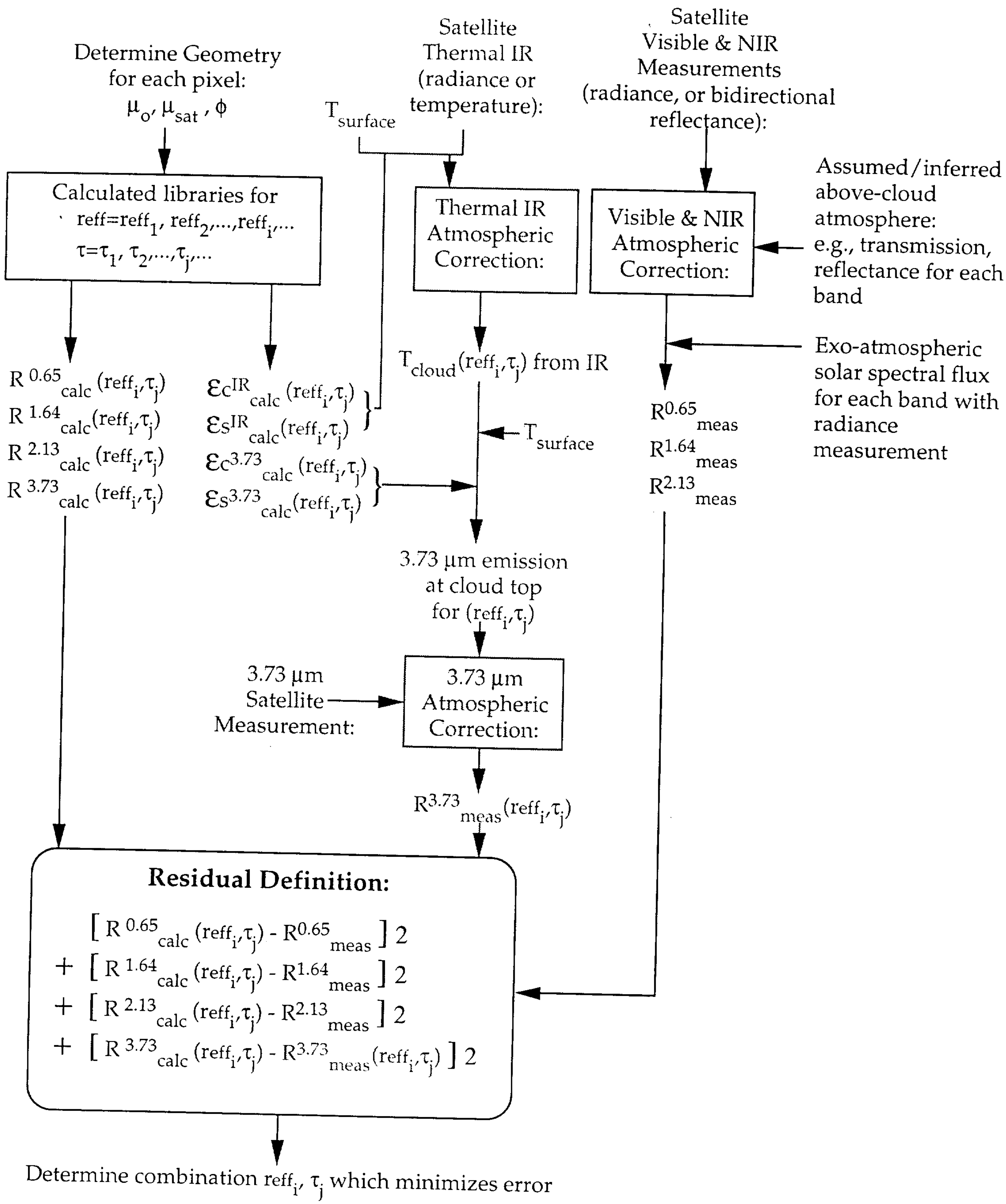
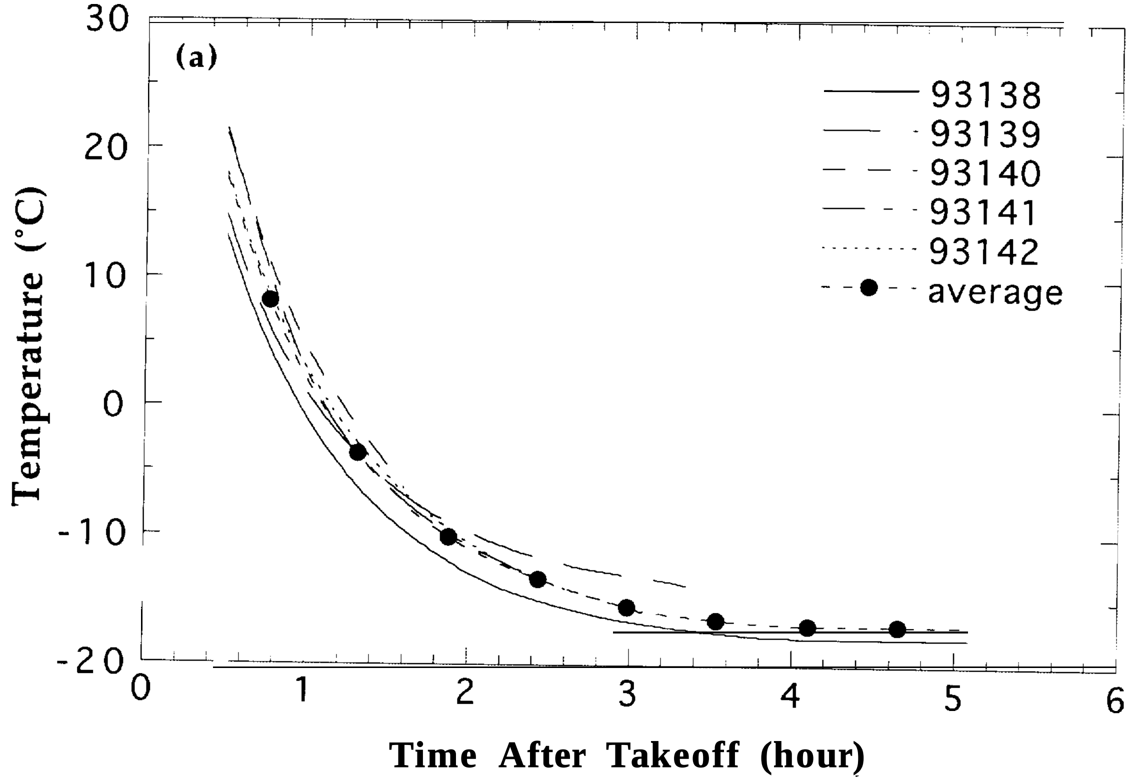


Figure 1b. Schematic for cloud retrieval algorithm in determining best fit for optical thickness and effective particle radius.



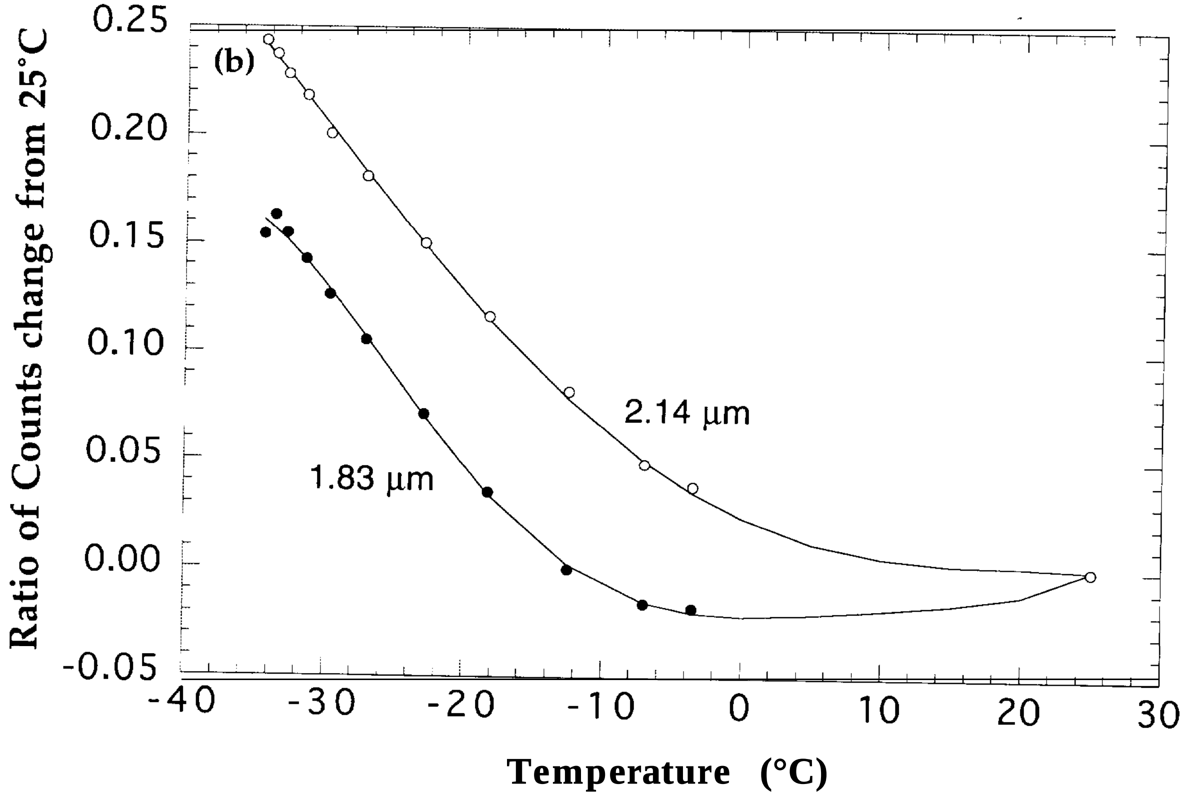


Figure 2. (a) Rustrak temperature data for five flights during the SCAR-A deployment and (b) temperature sensitivity of MAS 1.83 µm and 2.14 µm channels in cold chamber tests.

Figure 3. FIRE-II Cirrus IFO over the area of gulf of Mexico, by the MAS (left) and CLS (right) onboard NASA ER-2 aircraft. The MAS image has been re-sampled so that the spacing between the center of each pixel is 64 meters (a total domain size of 37 km by 64 km). The CLS vertical profile is at nadir direction which is along a line down the center of the MAS image.

Figure 4. Multi-level clouds acquired on December 5, 1991, during FIRE-II Cirrus IFO over the area of gulf of Mexico by the MAS onboard NASA ER-2 aircraft. The direction of flight is from top to bottom. Nadir is along a line down the center of the image. The image has been re-sampled so that the spacing between the center of each pixel is 64 meters (a total domain size of 37 km by 64 km).

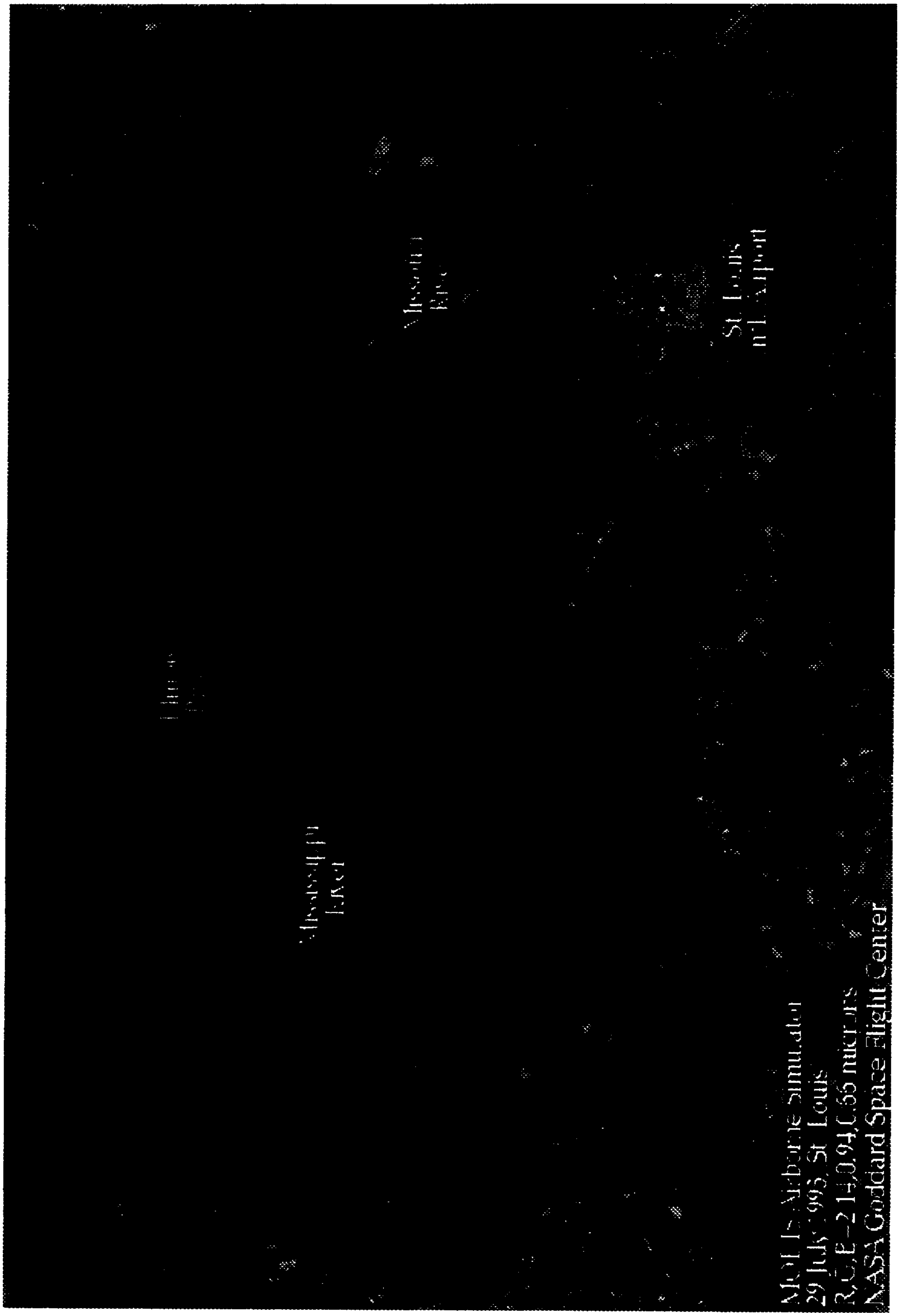


Figure5. Flood of 1993, St. Louis Missouri acquired on July 29 by the MAS onboard NASA ER-2 aircraft. The direction of flight is from right to left. Nadir is along a line across the center of the image. The image has been re-sampled so that the spacing between the center of each pixel is 64 meters (a total domain size of 64 km by 37 km). At the lower right the city of St. Louis is visible.

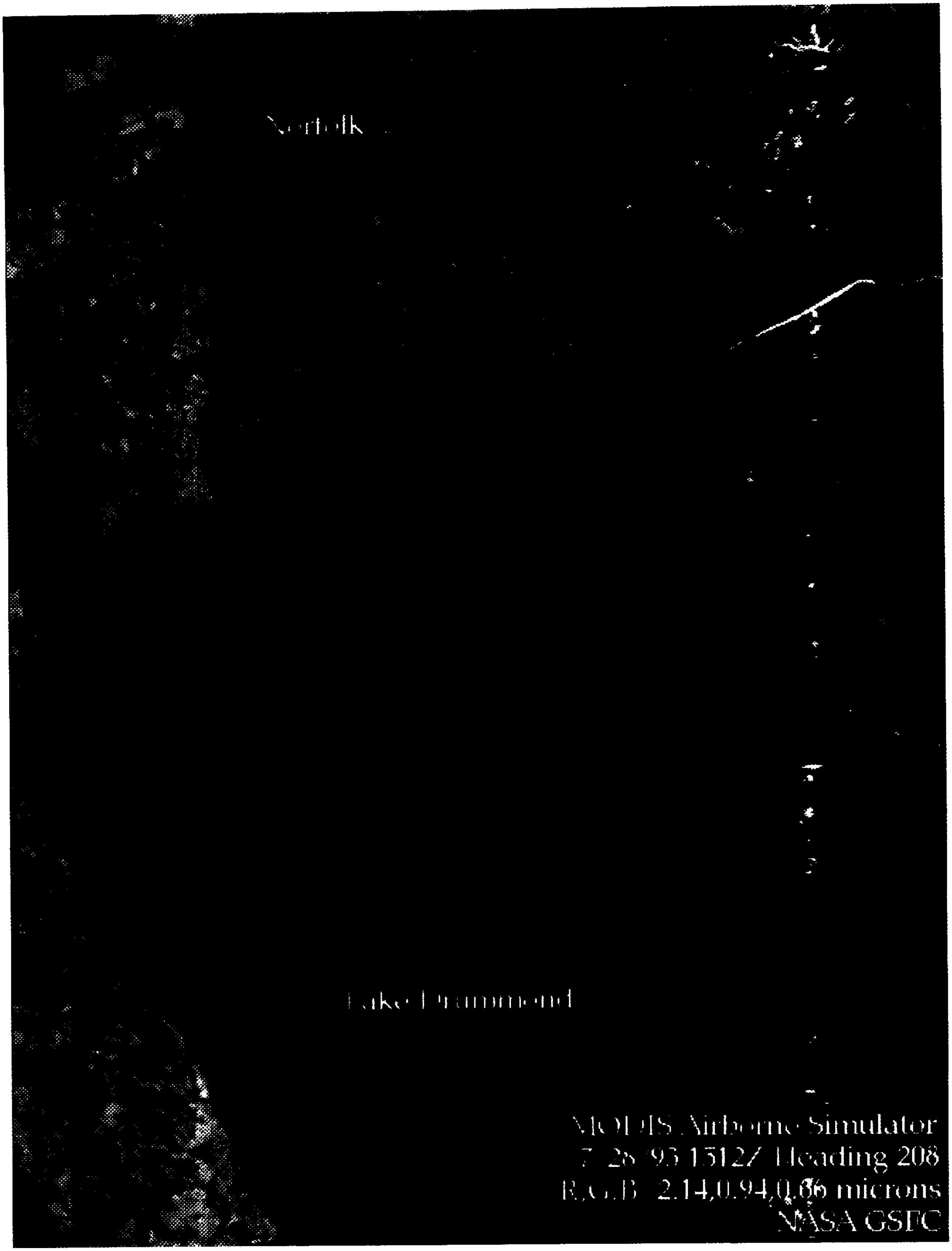


Figure 6. Surface features over the Great Dismal Swamp area acquired on July 28,1993, during the SCAR-A experiment, by the MAS onboard NASA ER-2 aircraft. The direction of flight is from top to bottom. Nadir is along a line across the center of the image. The image has been re-sampled so that the spacing between the center of each pixel is 64 meters (a total domain size of 37 km by 50 km). At the upper left the city of Norfolk is visible.

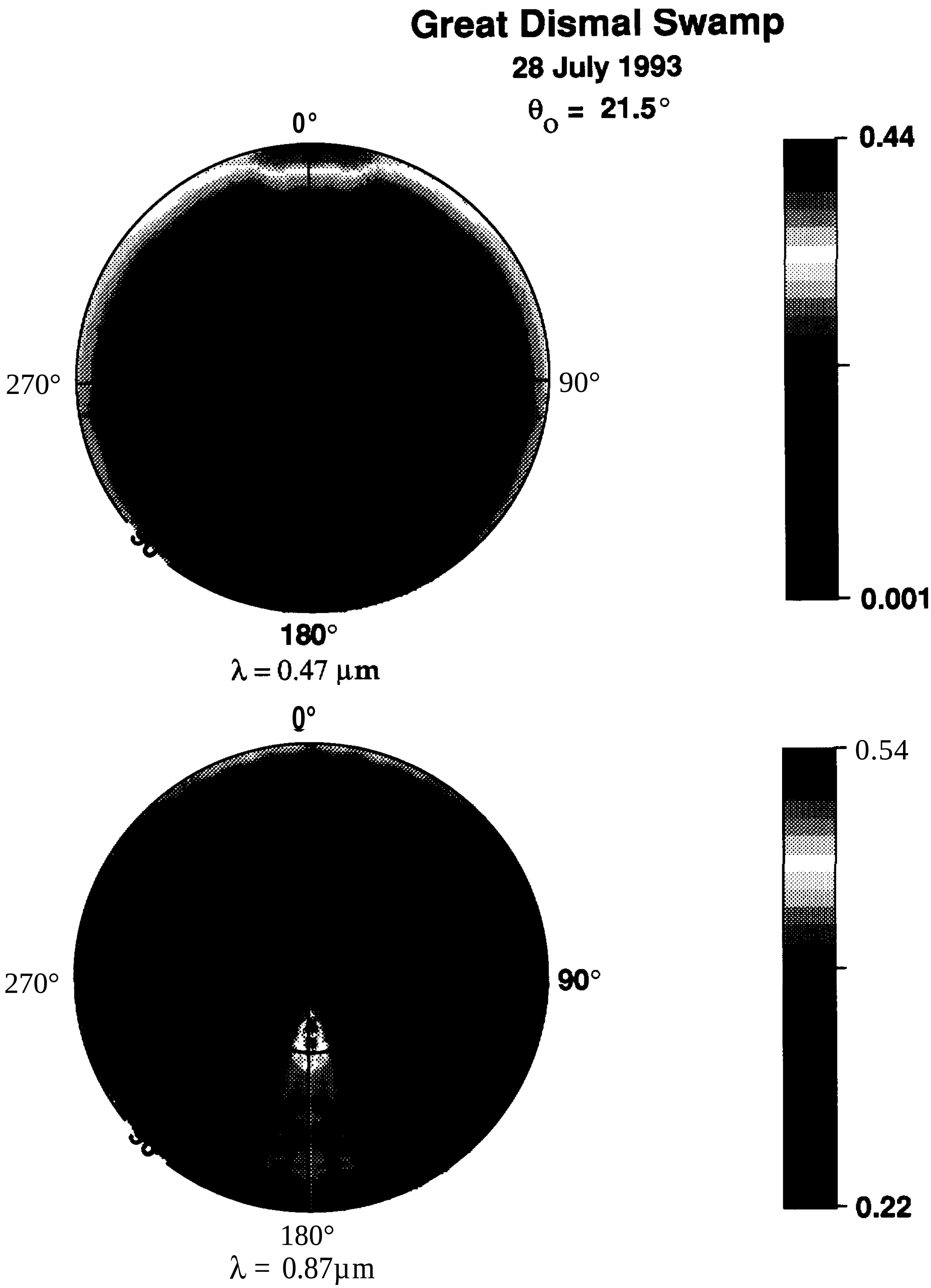


Figure 7a. Bidirectional reflectance of 0.47µm and 0.87 µm bands over the Great Dismal Swamp area acquired on July 28, 1993, during the SCAR-A experiment, by the CAR onboard University of Washington’s C-131A research aircraft.

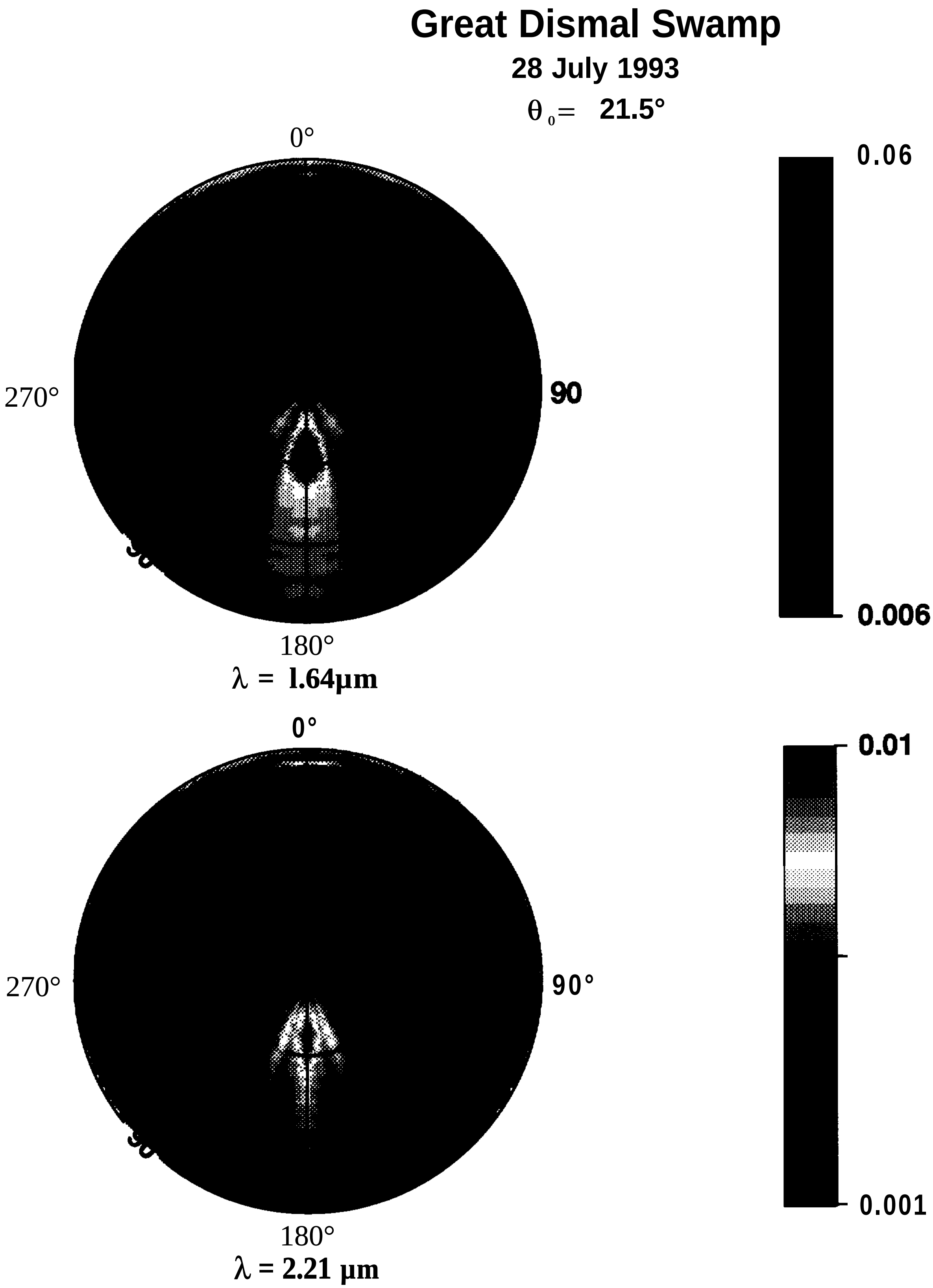


Figure 7b. Bidirectional reflectance of 1.64 μm and 2.21 μm bands over the Great Dismal Swamp area acquired on July 28, 1993, during the SCAR-A experiment, by the CAR onboard University of Washington's C-131A research aircraft.

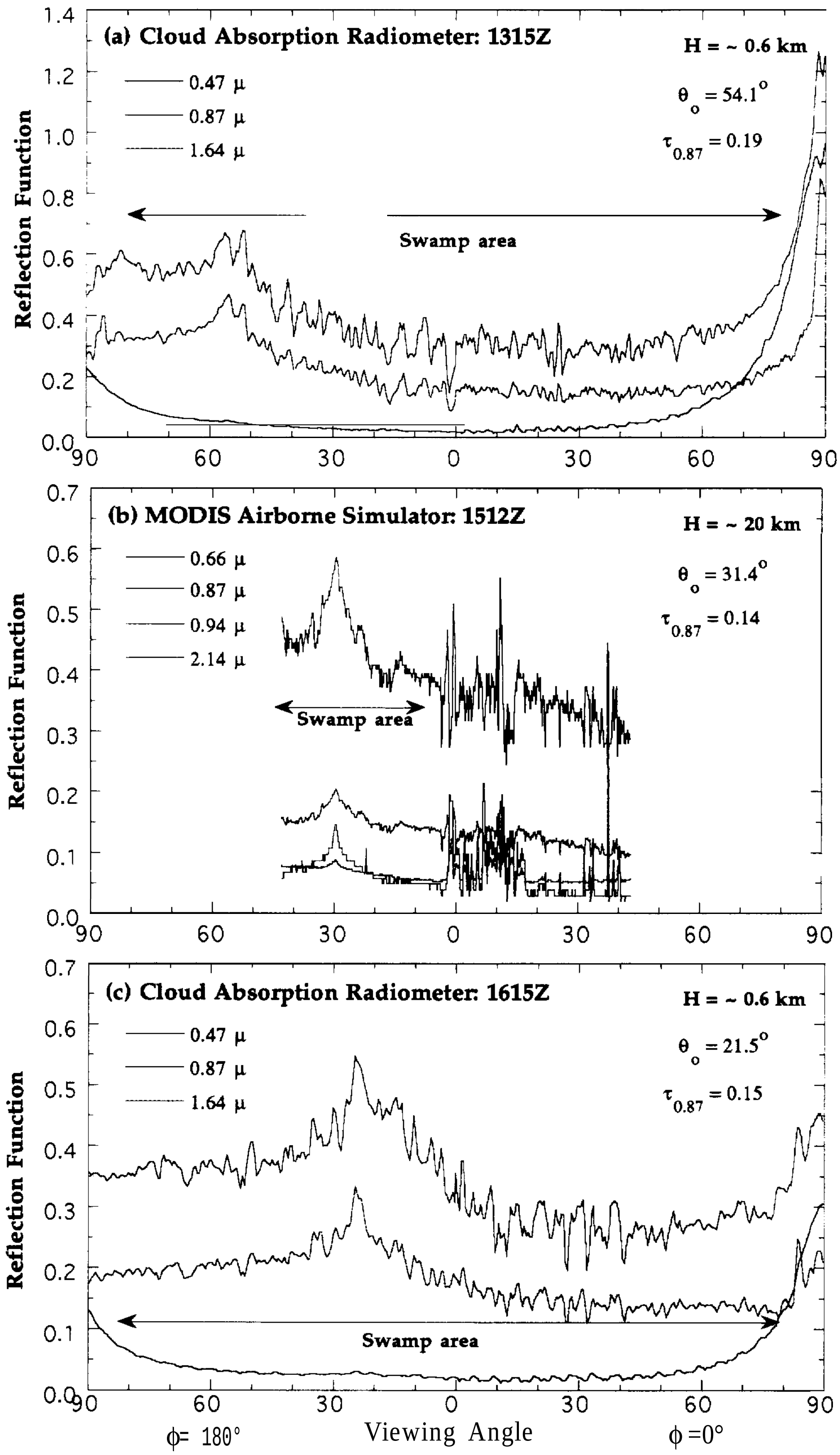


Figure 8. Reflection function measured in the principle plane for (a) 1315Z 28 July 1993 by CAR, (b) 1512Z 28 July 1993 by MAS, and (c) 1615Z 28 July 1993 by CAR.