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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 optical thickness and effective 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 reflectances. 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 Instrumental Research

A 50-channel digitizer with 12-bit resolution is currently being built to record MAS data for future deployments. Added to previous successful deployments, the MAS returned to Ames from the Pacific on April 8 following the TOGA COARE (Tropical Ocean Global Atmosphere/Coupled Ocean-Atmosphere Response Experiment, based in Townsville, Australia during January and February 1993) and CEPEX (Central-Equatorial Pacific Experiment, based in Nadi, Fiji during March and April 1993) campaigns. The MAS was tested on April 22 by Ken Brown for reflective channel calibration of the signal gain and offset with the GSFC hemisphere as a controlled input source. Then, shortly afterward, on April 28, the MAS was flown by Ames Research Center for a Lockheed program and on April 30 a flight over the snow test site selected by Dorothy Hall. Due to the heavy schedule of MAS usage, we have found that several parts of the system have degraded. The system was sent for emergency repair to Dædalus Enterprises for (i) liquid nitrogen dewar hold time problems and (ii) a failing in coating of the pfund optics assembly.

From late January to early April 1993, the MAS performed successfully during the TOGA COARE and CEPEX field experiments. We have found that the worst problems with MAS, which can be corrected, were the dewar hold time. The dewar on port 3 (3.725 μm) generally held for 3 to 4 hours and the one on port 2 (1.623-2.142 μm) for 4 to 5 hours after takeoff. After the dewars ran dry, these channels ceased to operate correctly; either saturated or became obscured by noise. The port 4 dewar (8.563-13.952 μm) had no problems and generally held for 7 to 8 hours after takeoff. Don Smyrl of NASA Ames Research Center pumped down the dewars in TOGA COARE but this did not seem to improve the hold times in dewars 2 and 3. Apparently, there was a leak in these two dewars, which were manufactured by the same contractor. During CEPEX, John Bush of NASA Ames found that the hold times in dewars 2 and 3 degraded further and the hold time for dewar 4 also decreased. Minor problems in recording MAS navigation data were encountered during two of the last four TOGA COARE flights (flights 93-065 and 93-066). These problems were overcome by swapping Exabyte recorders and by obtaining time, latitude, longitude, heading, altitude, roll and pitch data from the Cloud Lidar group at GSFC.

In TOGA COARE, prior to the 93-066 flight (February 23, 1993 local time), the gain settings in channels 2, 3, and 4 were set to 2 if the takeoff was after 10:30 AM local time and 1 if before 10:30 AM takeoff. This was because brighter convective clouds were being observed in the morning. For flights 93-066 and 93-067 (February 23-24 local takeoff) the gains in channels 2, 3, and 4 were set to 2 and the gain in channel 8 was changed from 4 to 8 to maximize the signal resolution. Based on the suggestion of Chris Moeller, an atmospheric transmittance code (modified from LOWTRAN7) was run by Si-Chee Tsay in Fiji to examine the changes of channel 5 band center from 1.83 to 1.88 μm. This change resulted in a spectral shift further into a water vapor absorption band that was expected to enhance the ability to detect thin cirrus clouds at high altitudes. This change was effective in the CEPEX deployment. After MAS returned from CEPEX, a failing in the coating of the pfund optics assembly was discovered. The system was sent for emergency repair to Dædalus Enterprises to correct this problem prior to the deployment in the SCAR-A (Sulfate, Clouds And Radiation - America) experiment in July, 1993. The detectors were swapped out and reassembled, following which the spectral response tests were performed after the dewars were repaired. We believe that the system will be back to better than its past performance in ports 2-4. Also, a broader waveband first dichroic was installed in MAS to improve the SWIR performance at no decrease in thermal channel sensitivity.

The modification work of the CAR (Cloud Absorption Radiometer) was completed in time for an early July integration into the University of Washington's C-131A for the SCAR-A experiment. This work includes: (i) a replacement of the Stirling-cycle cooler and near-infrared indium antimonide (InSb) detector, no longer requiring a source of high-pressure nitrogen gas during field experiments, (ii) upgrades of the dichroic beamsplitters and lenses, which have degraded and aged over the 10 years of field use of the radiometer; and (iii) a newly developed Automatic Calibration System, which will be used to calibrate the CAR in front of the Goddard 6' integrating sphere and 4' integrating hemisphere.

The Stirling-cycle cooler and InSb detector assembly is larger than the previous one which had additional tubes to the external high-pressure nitrogen gas supply. Ken Kirks modified, assembled and installed this new SWIR subassembly into the CAR. Preliminary performance tests of this detector revealed very low noise signals. On the optical side, the transmission and reflection scans of the dichroic beamsplitters and the lenses from the manufacturer look very good in meeting all of the wavelength specifications. We have also received the uv-B filter that enables the uv radiation to transmit through the optical chain to the detector. The technique to calibrate the CAR in the uv has not yet been worked out, but will be explored by the CAR Instrument Scientist (Nita Walsh) during the next quarter. The Automatic Calibration System designed and installed by Max Strange is now operational. John Cavanaugh (Code 924) and Tom Arnold (ARC) have worked on the data system (interface and analog to digital conversion) to record and display the calibration data. This data system was used in a preliminary calibration of the CAR (before adding the new optics) and worked quite well. Two minor problems occurred: (i) when switching the CAR from gain level 7 to gain level 1, typically some of the high values from the gain level 7 data were included in the averaging of the gain level 1 signals; and (ii) the calibrator does not output data if the signal is below a certain threshold during a scan and thus offset values (intensity at zero lamps) for each channel are not recorded. These problems will be corrected before the SCAR-A deployment in July.

b. MODIS-related Algorithm Study

Work in refining and extending the retrieval algorithm developed by Nakajima and King for determining the cloud optical thickness and effective radius of clouds from reflected solar radiation measurements is being pursued by Si-Chee Tsay. This program has thus far been applied to 2 channels of the MAS, but will in the future be extended to multiple wavelengths appropriate for MODIS. A reduction of angular information, previously generated for every 2° angular resolution and stored in the code for use by the retrieval algorithm, should be sought in order to increase the capacity for processing multispectral information.

To study atmospheric corrections, several models developed by Si-Chee Tsay such as the radiative transfer codes DISORT (Discrete Ordinate Radiative Transfer, versions 1 and 2), the atmospheric transmittance codes (TransL and

TransM, modified from LOWTRAN7 and MODTRAN), and the Mie scattering codes (Aerosl) including stratified structures, relative humidity growth rate, mass mixing and complex angular momentum (CAM) theory, were all installed, compiled and run on our SGI "RedBack" workstation by Liam Gumley to establish familiarity with their operations and to compare other results. Cases were run with and without aerosol scattering over non-reflecting and Lambertian reflecting surfaces. Results showed good agreement with the single scattering model (for a non-reflecting surface). This work will further be extended to derive an accurate and efficient atmospheric correction scheme, including Rayleigh scattering and aerosol extinction, for MAS (and subsequently MODIS) data.

One of the most difficult problems in the retrieval algorithms is the existence of multilayer cloud systems such as thin cirrus clouds overlying boundary layer stratus clouds. Preliminary work was begun on analyzing the properties of thin cirrus clouds observed on December 5, 1991 over the Gulf of Mexico by Liam Gumley. Data for this task were obtained from the MAS, AVIRIS (Airborne Visible/Infrared Imaging Spectrometer), HIS (High-resolution Interferometer Sounder), and CLS (Cloud Lidar System). The MAS flight tracks were examined to determine which were suitable for analysis. Flight tracks 3 through 6 were selected, as each of these had scan directions that were approximately normal to the principal plane of the sun. This simplifies the interpretation of the visible and near-infrared data since reflection from the sea surface is minimized. The visible and IR quick looks for these flight tracks revealed that adjacent areas of thin cirrus and clear sky were observed. These will be used for further investigation.

c. MODIS-related Services

Michael King, Tom Arnold, Liam Gumley and Si-Chee Tsay spent a month of their time participating in two field experiments, as described below.

1. TOGA COARE experiment

One of the major TOGA COARE objectives was to improve our understanding of the role of the western tropical Pacific Ocean warm pool on the mean and transient state of the tropical ocean/global atmosphere system. TOGA COARE consisted of numerous coordinated research flights over convective clouds in the intensive flux array, with the NASA ER-2 and DC-8 aircraft playing the remote sensing role and the NOAA P-3s and NCAR Electra the in situ and boundary layer roles. The main research interests of our group were: (i) acquiring high quality multispectral imagery of high altitude cirrus clouds from the MAS mounted on the ER-2 with nearly simultaneous in situ microphysical measurements obtained from the DC-8, and (ii) mapping the cloud boundaries, especially if multilayered clouds were present, using nadir propagating lidar from the ER-2 (to map cloud top boundaries), and zenith propagating lidar measurements from the DC-8 (to map cloud base altitude and structure).

During the entire 6 weeks that the NASA aircraft participated in COARE, 13 research flights were conducted with the DC-8 aircraft, 11 of which were coordinated with the ER-2. Michael King was the flight scientist for the NASA ER-2 aircraft for one of these flights, and mission scientist for the DC-8 coordinating the overall mission (February 24). Highlights of this flight are as follows:

- Coordinated flight between the ER-2 and DC-8 over the ground site at Kavieng, Papua New Guinea, consisting of 5 overflights of the ground site.
- The ER-2 flew 150 km legs perpendicular (2.5 legs) and parallel (2.5 legs) to the plane of the sun.
- The DC-8 flew one leg within the cirrus clouds (to measure microphysics) and one leg below (to map cloud base altitude using the zenith propagating lidar), for each 150 km leg parallel and perpendicular to the sun.
- The cirrus consisted of many levels, and was composed of hexagonal crystals, as evidenced by a 22° halo, sun dogs, and a sun pillar. The lower-layer water cloud often showed a glory as well.
- The MAS imagery showed the glory from the lower level water clouds quite well in the visible channels, since those channels saw through the semi-transparent cirrus clouds. The thermal channels clearly showed the upper layer cold cirrus cloud.
- The ground-based observations also included Jim Spinhirne's lidar developed by the Director's Discretionary Fund at Goddard. Thus Spinhirne had lidars on the ER-2, DC-8, and ground site simultaneously.
- The DC-8 lidar picked up the contrail of the ER-2 overhead. This remarkable feat shows the extremely good coordination between these two aircraft in both speed and location, as the field of the view of the lidar telescope is extremely small.

Many cloud climatological regimes were encountered during this six week-long experiment, thereby providing a very useful data set for further study. In addition to the case study described above, there were 2 research flights conducted over the eye of Typhoon Oliver.

2. *CEPEX Experiment*

The primary research objectives of CEPEX were to test a cirrus thermostat hypothesis for regulation of sea surface temperature (SST) in the warm central Pacific Ocean, focusing the investigation on the water-vapor greenhouse effect and the role of tropical cirrus on radiation fluxes. We spent the first week in Fiji for CEPEX between March 7 and 12, 1993. During this time, one short ER-2 pilot qualification flight was conducted, which enabled us to assess the performance of the MAS and the data system in Nadi. The first research flight took off at the same time as our commercial airline departed. Before leaving, however, Liam Gumley showed 2 scientists in Prof. Ramanathan's group how to look at MAS data after each flight, thereby permitting a scientist to evaluate the scientific content of each flight.

During the entire CEPEX deployment from March 7 to April 6, 12 research flights were conducted with the NASA ER-2, NOAA P-3 and Aeromet's Learjet aircraft, including the R/V Vickers ship. Francisco Valero of NASA Ames was the flight scientist for the NASA ER-2 aircraft for all 12 flights. Three case study dates were proposed for validation (March 15, 25, and April 3; all dates are GMT dates) at the upcoming CEPEX meeting, to be held from August 10-12, at which Si-Chee Tsay will present some preliminary results acquired by the MAS. Highlights of these flights are as follows:

- On March 15, a coordinated flight between the ER-2 and Learjet was along the eastern track, well coordinated vertically; the NOAA P-3 flew the west pennant for rendezvous with R/V Vickers at 167.2°W.
- On March 25, the ER-2 and Learjet flew partially coordinated flights on the western track, which was a good day for anvil heating and cloud forcing; the P-3 flew from Christmas Island to Kwajalein along 2°S.
- On April 3, a coordinated flight between the ER-2, Learjet and P-3 stacked along the western track up beginning at 172.5°E and flew along 2°S, a good research day for deep convective system, the f-factor evaporation under disturbed conditions, albedo of cirrus, and cirrus heating rates. During this mission, the ER-2 underflew both Landsat and NOAA-11 satellites.

The above dates have been selected for intercomparison of platforms only. Other dates for individual analyses are also selected: for example, April 4 is a good date for microphysics analysis from the Learjet data.

3. *Meetings*

1. Michael King attended the first SeaWiFS Science User's Group meeting in Annapolis, MD on January 19 and spent nearly 1 hour discussing various scenarios for convergence of the NOAA afternoon polar orbiter series with the EOS PM series (PM-2 and PM-3) with Dr. Kathryn Sullivan (Chief Scientist of NOAA).

2. Michael King worked with the new EOS Color Project Scientist and the EOS Chemistry and Special Flights Project to better define the EOS Color mission, aimed at deriving ocean color and phytoplankton pigment concentrations in concert with MODIS, prior to the launch of EOS PM-1 (thereafter providing 2 MODIS sensors in orbit).

3. Michael King served as the flight scientist for the NASA ER-2 and mission scientist for the DC-8 aircraft in a coordinated multi-aircraft radiation flight during TOGA COARE. This radiation mission was very successful. Many optical phenomena in the atmosphere, such as a 22° halo, sun dogs, a sun pillar and a glory were observed and measured by MAS and other instruments.

4. Michael King chaired the MODIS Science Team Meeting for the Atmospheric Group, held on March 24-26 at the Holiday Inn, Greenbelt, MD.

5. Michael King co-chaired the EOS Investigators' Working Group Meeting and participated in the Payload Advisory Panel meeting at the Greenbelt Marriott, Greenbelt, MD on March 29-April 1.

6. Michael King and Si-Chee Tsay attended the SCAR-A (1993-Wallops Island) and SCAR-B (1995-Brazil) Mission Planning Workshop, held on April 27-28 at the Holiday Inn, Greenbelt, MD.

7. Michael King attended the AM Project Development meeting and the SWAMP meeting organized by Piers Sellers to discuss issues of concern to the EOS AM Platform.

8. Michael King and Si-Chee Tsay attended the EOS Aerosol Topical Science Workshop, held May 17-18 at Martin's Crosswinds, Greenbelt, MD. Michael King described the MAS and CAR instruments and gave examples of their application to MODIS and MISR algorithm development.

9. Michael King and Si-Chee Tsay attended the ASTEX Working Group Meeting from May 24-25 at the Inner Harbor Marriott, Baltimore, MD, where King led a small working group on radiation and microphysics research.

10. Michael King and Si-Chee Tsay attended the Office of Naval Research Shiptrack Workshop on May 26 at the Holiday Inn - Inner Harbor, Baltimore, MD, where the radiation measurement capability of the ER-2 and C-131A were described.

11. Michael King and Si-Chee Tsay attended the CERES IDS Review and Science Team Meeting, held on June 8-11 at the Fort Magruder Inn, Williamsburg, VA.

4. Seminars

1. Michael King gave a 1 hour seminar at Hughes Information Technology Center, the EOSDIS Core System Contractors, on EOS.

2. Michael King attended the Global Change Policy Symposium held at the National Press Club in Washington, DC on May 18, where he gave a presentation on "EOS Science Overview."

3. Michael King and Si-Chee Tsay attended the AGU Spring Meeting from May 24-28 at the Inner Harbor Marriott, Baltimore, MD and presented two papers.

4. Liam Gumley attended the FIRE Cirrus Science Conference from June 14-17 at Breckenridge, CO and presented a paper.

III. Data/Analysis/Interpretation

a. Data Processing

The MAS Exabyte tapes, acquired during the TOGA COARE and CEPEX deployments, were received from NASA Ames Research Center. One of the most interesting dates (February 24) of TOGA COARE was quickly processed by using preliminary calibration data. Figure 1 shows the glory feature from the low level water clouds. The ER-2 flew from North (top) to South (bottom) at a return track (zenith angle about 15 degrees). Unfortunately, it was late in the flight and exceeded the dewar hold time for ports 2 and 3. Only the visible and LWIR data are usable. More careful analysis should be possible using visible channels alone to derive the cloud particle size from the glory width.

The MAS does not have onboard calibration for the visible and near-infrared spectral regions. The temperature of the MAS in-flight can drop to as low as –45°C, significantly colder than the +25°C laboratory calibration. Results of the Ames cold chamber tests suggest appreciable change with instrument temperature for the MAS 1.6 and 2.1 µm channels. To complete the MAS calibration, Tom Arnold, Dave Augustine (a new member of my group) and Liam Gumley have worked on decoding blackbody and instrument Rustrak temperature data from the complete set of FIRE Cirrus II, ASTEX and TOGA COARE Level-0 tapes. Detailed analysis and interpretation of the results are given in section (b) below. Tom Arnold has nearly completed the first draft of the "MAS visible and near-infrared calibration: 1992 ASTEX field experiment" for review and publication.

Liam Gumley completed the first draft of the "MODIS Airborne Simulator Level-1B Data User's Guide." This document, together with the "MODIS Airborne Simulator Level-1 Processing User's Guide," were given to the MODIS SDST for review before publication as official MODIS reports. The first report describes the MAS instrument, the calibration and geolocation procedures, the Level-1B data contents, and instructions on how to use netCDF. The second one shows all the steps in the processing sequence, and includes sample command syntax, program descriptions, a glossary of terms, and MAS specifications and data formats. Also, the MAS Level-1 Processing System source code was packaged and handed over to the new maintainer (Paul Hubanks, MODIS SDST). Both the PC (MSDOS) and Iris/Indigo (Unix) versions were delivered along with compilation instructions and scripts.

Ward Meyer and Dave Augustine worked closely on our archive system of raw and processed (active scan) CAR data. Ward Meyer has processed some of the LEADEX (Lead Experiment, conducted in the Beaufort Sea, Alaska during April 1992) surface bidirectional reflectivity of multi-year snow/ice and snow over tundra, obtained by the CAR. Polar contour plots for a new set of angular distribution cases were processed through program CARASPLT, Spyglass (Transform and Format) and MacDraw Pro. A detail discussion is presented below.

b. Analysis and Interpretation

The first phase of a comparison between MAS, AVIRIS, and HIS radiances from FIRE Cirrus-II in November/December 1991 was conducted by Liam Gumley to access the calibration accuracy of the MAS visible/near-IR and LWIR channels against instruments with known calibration accuracy. Initial results showed a problem with the calibration of the MAS channels 5 and 6 due to the temperature dependent gain correction applied to MAS data. To examine the temperature sensitivity of MAS data, the Rustrak temperature (near the detector) and the ambient blackbody data for FIRE Cirrus II, ASTEX, and TOGA COARE were processed and analyzed by Tom Arnold and Dave Augustine (see Figure 2).

The Rustrak temperatures generally show a sharp decrease in the temperature of the MAS during the first 2 hours in flight and are generally much warmer than the corresponding blackbody temperatures. To properly account for the temperature sensitivity, we have to analyze: (i) what is the best measure of MAS instrument temperature, and (ii) how to determine the instrument temperature if the Rustrak data are not available. We have decided that the MAS temperature would be the best represented by an average curve of available Rustrak data for each deployment. Thus for FIRE Cirrus II, ASTEX and TOGA COARE, data were averaged and a curve of MAS temperature versus time was produced for each deployment. Then using a polynomial curve fitting technique, equations were derived for each curve. These equations will be used in the MAS level-1B data processing to calculate MAS temperature.

Figures 3 and 4 show the comparisons of MAS and AVIRIS SWIR and visible radiances, respectively, from the FIRE Cirrus II ER-2 measurements on December 5, 1991 over many different uniform targets. In Figure 3, the agreements between MAS and AVIRIS radiances are within 3-5% (slope), if the temperature dependent gain is accounted for. This shows a big improvement as comparing to results with no temperature correction of 15-25%. Figure 4 shows no temperature sensitivity in the visible channels and the comparison is in excellent agreement between the MAS and AVIRIS. In a similar manner, a comparison of data from the MAS and HIS is underway to establish the calibration accuracy of the MAS IR channels. Further work is underway to more fully assess the overall calibration accuracy of the MAS, and to understand the problems that have been discovered.

Surface spectral reflectance is a major parameter of interest to the biospheric sciences, remote sensing, 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. During the last several years, many angular distributions of surface reflectances have been obtained by the CAR onboard the University of Washington's C-131A research aircraft. The instrumentation and operation specifications of CAR in measuring the surface bidirectional reflectance is shown in Figure 5.

Two types of surface bidirectional reflectance patterns were measured in this manner and analyzed by Si-Chee Tsay: (i) multi-year snow and sea ice, and (ii) snow over tundra, as shown in Figures 6 and 7, respectively. Figure 8 shows the detailed structure of the reflection function measured in the principle plane. From these observations we draw the following conclusions: (i) in the visible and near-infrared spectral range, the reflection function of multi-year snow and sea ice is greater than that of snow over tundra; (ii) the specular reflection and hot spot (direct backscattering or opposition effect) around the principal plane are clearly visible; (iii) nearly isotropic scattering occurred at all viewing angles except near the forward and backward directions. However, multi-year snow and ice revealed larger variability due to higher spatial inhomogeneity. Based on these measurements, results from various surface bidirectional reflectance models will be further studied.

Da-Sheng Feng has studied extensively the statistical relationship between cloud optical and radiative properties (e.g., single scattering albedo, similarity parameter) and cloud droplet size parameters (e.g., effective radius, cross-section area, and total volume). The CAR radiance fields of FIRE-87 Flight 1301 (July 10, 1987), which contained seven flight sections in the diffusion domain of those clouds (including two ship track cases) that measured deep within a cloud layer, were used to infer the cloud optical and radiative properties by applying asymptotic theory. Individual droplet size distributions and corresponding diffusion domain scans were used for data analysis. This approach is very time-consuming. Relevant CAR analysis programs, previous developed by Michael King and Ward Meyer, were modified, integrated and run on the Cray-YMP to serve for this task. Preliminary results reveal that the cloud single scattering albedo may have more consistent relationship with the total droplet surface area than with the particle effective radius. The scattergrams correlating cloud single scattering albedo and particle effective radius show some unexpected noise. Questions are now being raised as to how reliable these size distributions are, as well as the tightness of the diffusion domain criteria that have been applied to the data thus far. Further and detailed studies are needed to come to a conclusion. Analysis has also begun on an interesting ice cloud case measured in Flight 1546 of LEADEX. This may well be in a diffusion domain in ice cloud which was the first time measured by the CAR.

IV. Anticipated Future Actions

a. participate in the SCAR-A campaign, taking place July 10-28 from NASA Wallops Flight Facility, VA and the follow-up data analysis;

b. attend the CEPEX workshop, to be held on August 10-12 at the Scripps Institution of Oceanography, La Jolla, CA;

c. attend the CERES Cloud Working Group Meeting, to be held on September 20-22 in Denver, CO;

d. attend the WESTEX (West Coast Shiptrack Experiment) Workshop, to be held on September 22-23 at the Naval Postgraduate School, Monterey, CA;

e. 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;

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

g. continue to analyze MAS data sets obtained from the FIRE-II, ASTEX, TOGA COARE, CEPEX and upcoming SCAR-A field campaigns.

V. Problems/Corrective Actions

No problems that we are aware of at this time.

VI. Publications

1. Harshvardhan, and M. D. King, 1993: Comparative accuracy of diffuse radiative properties computed using selected multiple scattering approximations. *J. Atmos. Sci.*, **50**, 247-259.

2. King, M. D., L. F. Radke and P. V. Hobbs, 1993: Optical properties of marine stratocumulus clouds modified by ships. *J. Geophys. Res.*, **98**, 2729-2739.

3. King, M. D., 1993: Radiative properties of clouds. *Aerosol-Cloud-Climate Interactions*, P. V. Hobbs, Ed., Academic Press, 123-149.

4. King, M. D., and S. C. Tsay, 1993: Radiative and microphysical properties of marine stratocumulus clouds: Results from ASTEX. Presented at AGU Spring Meeting, May 24-28, Baltimore, MD.

5. Tsay, S. C., and M. D. King, 1993: Measurements of bidirectional reflec-

tivity over snow, ice, and other types of surfaces. Presented at AGU Spring Meeting, May 24-28, Baltimore, MD.

6. Gumley, L. E., M. D. King, S. C. Tsay, B. C. Gao, and G. T. Arnold, 1993: Intercomparison of MAS, AVIRIS, and HIS data from FIRE Cirrus II. Presented at FIRE Cirrus Science Conference, June 14-17, Breckenridge, CO.

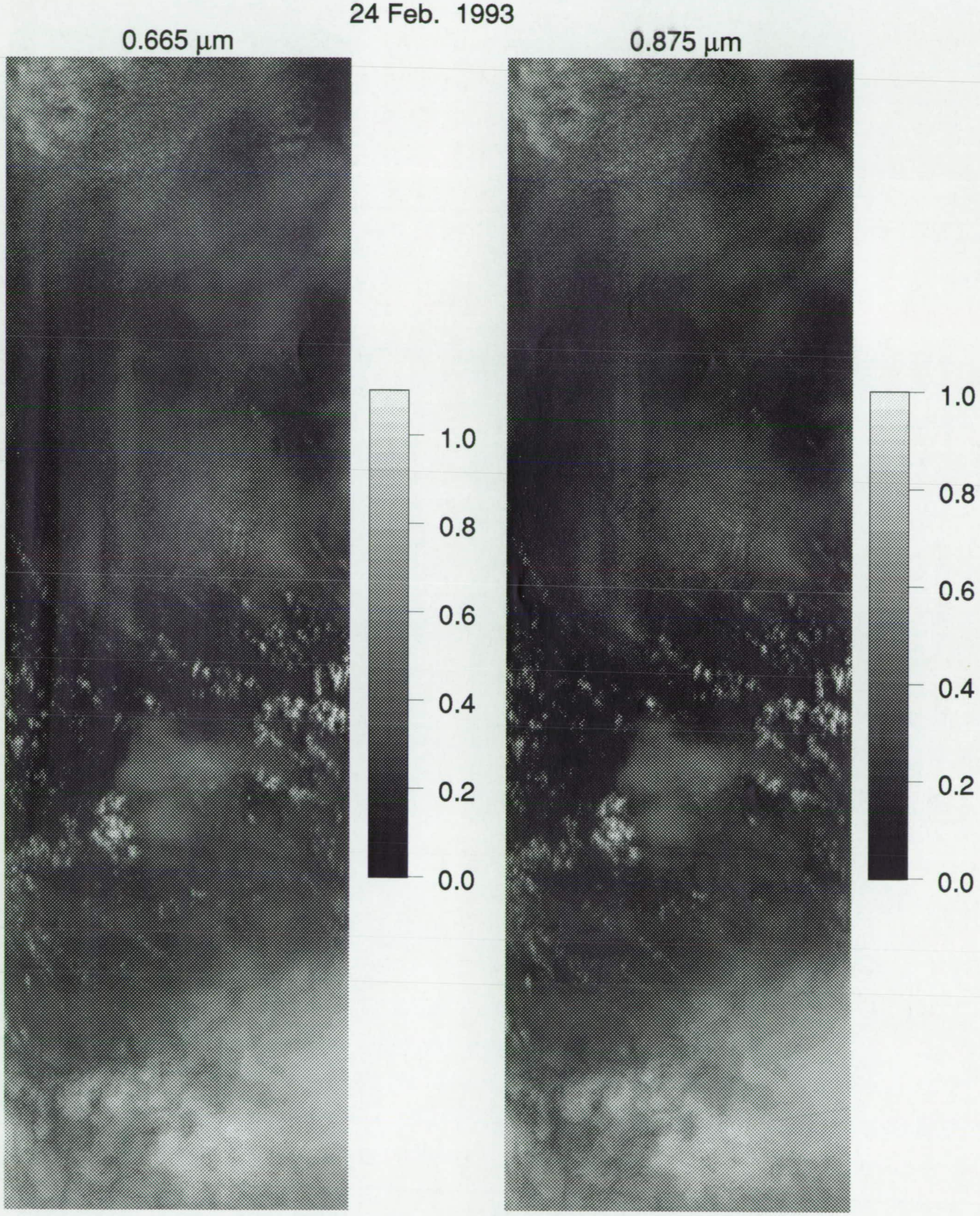
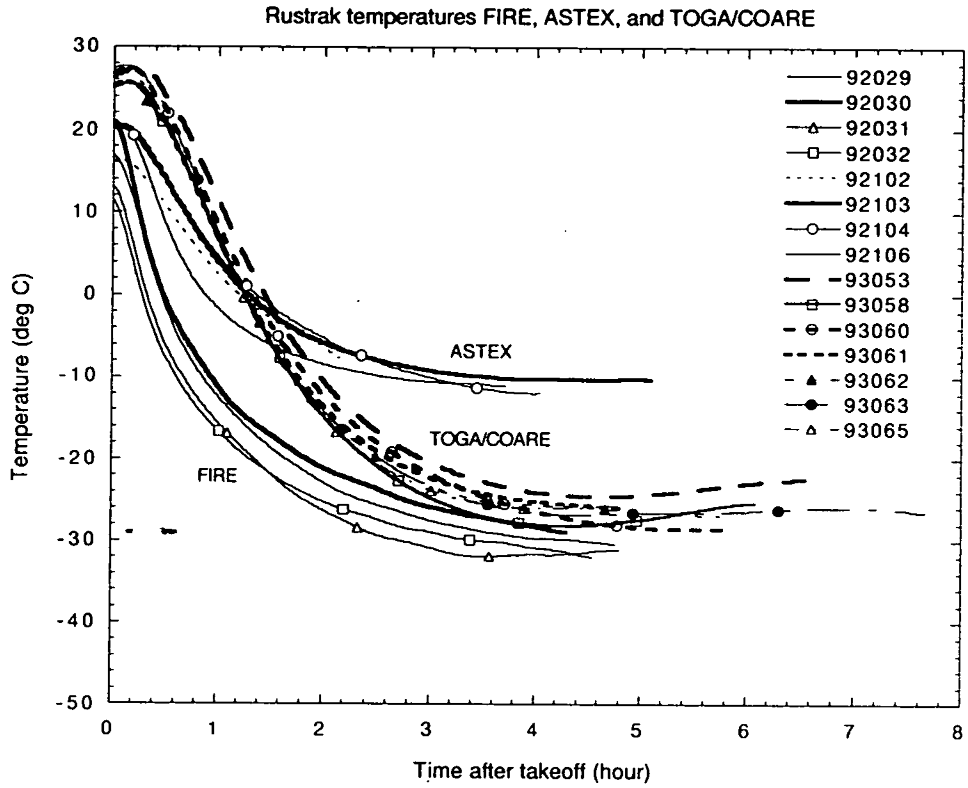


Figure 1.


Rustrak temperatures FIRE, ASTEX, and TOGA/COARE
Temperature (deg C)
Time after takeoff (hour)
30
20
10
0
-10
-20
-30
-40
-50
0
1
2
3
4
5
6
7
8
92029
92030
92031
92032
92102
92103
92104
92106
93053
93058
93060
93061
93062
93063
93065
ASTEX
TOGA/COARE
FIRE

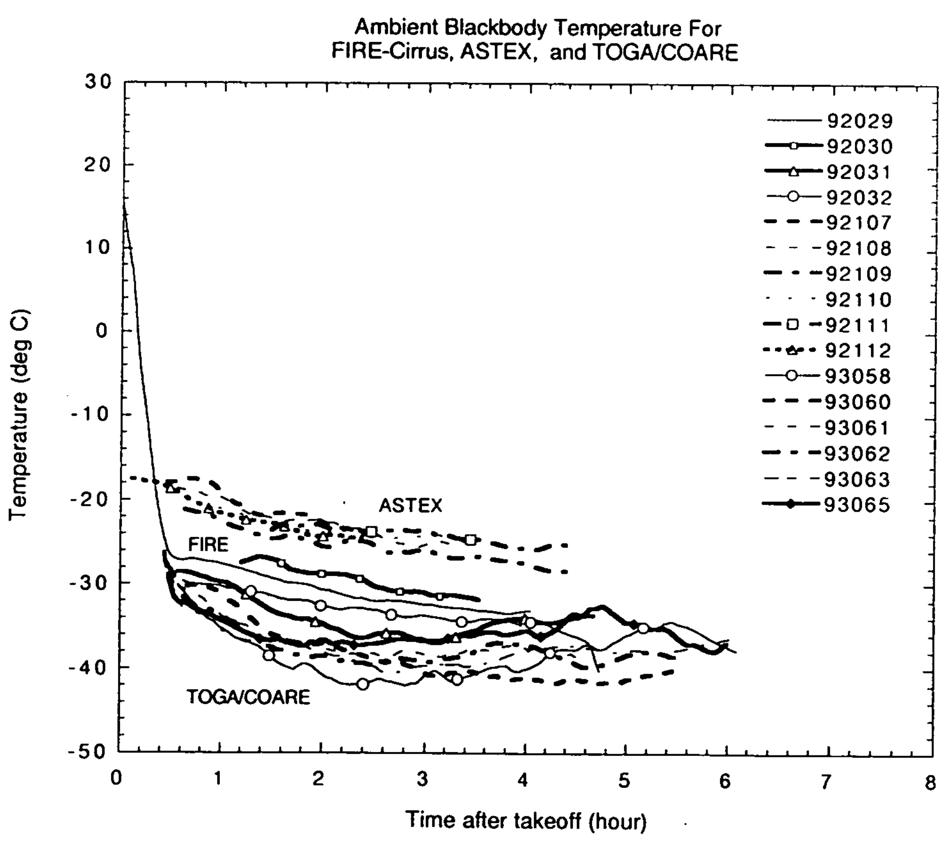
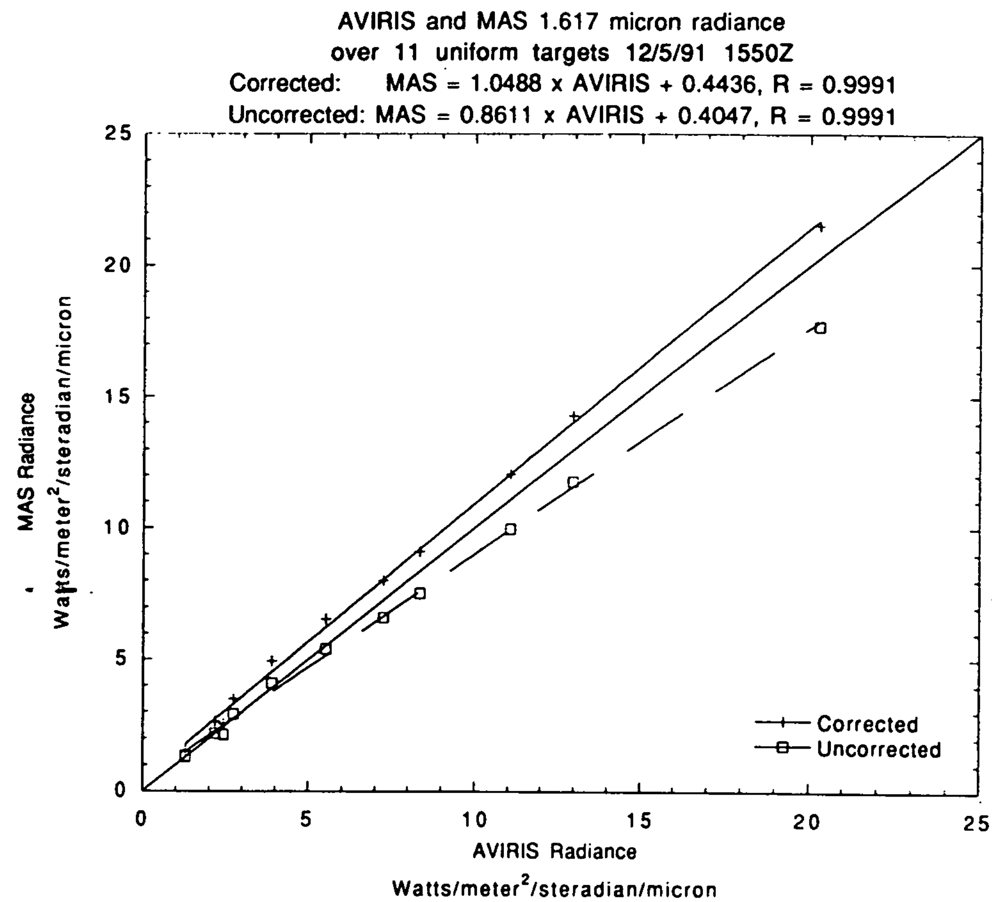

Ambient Blackbody Temperature For
FIRE-Cirrus, ASTEX, and TOGA/COARE
Temperature (deg C)
Time after takeoff (hour)
30
20
10
0
-10
-20
-30
-40
-50
0
1
2
3
4
5
6
7
8
92029
92030
92031
92032
92107
92108
92109
92110
92111
92112
93058
93060
93061
93062
93063
93065
ASTEX
FIRE
TOGA/COARE

Figure 2.


AVIRIS and MAS 1.617 micron radiance
over 11 uniform targets 12/5/91 1550Z
Corrected: MAS = 1.0488 x AVIRIS + 0.4436, R = 0.9991
Uncorrected: MAS = 0.8611 x AVIRIS + 0.4047, R = 0.9991
MAS Radiance
Watts/meter²/steradian/micron
AVIRIS Radiance
Watts/meter²/steradian/micron
Corrected
Uncorrected

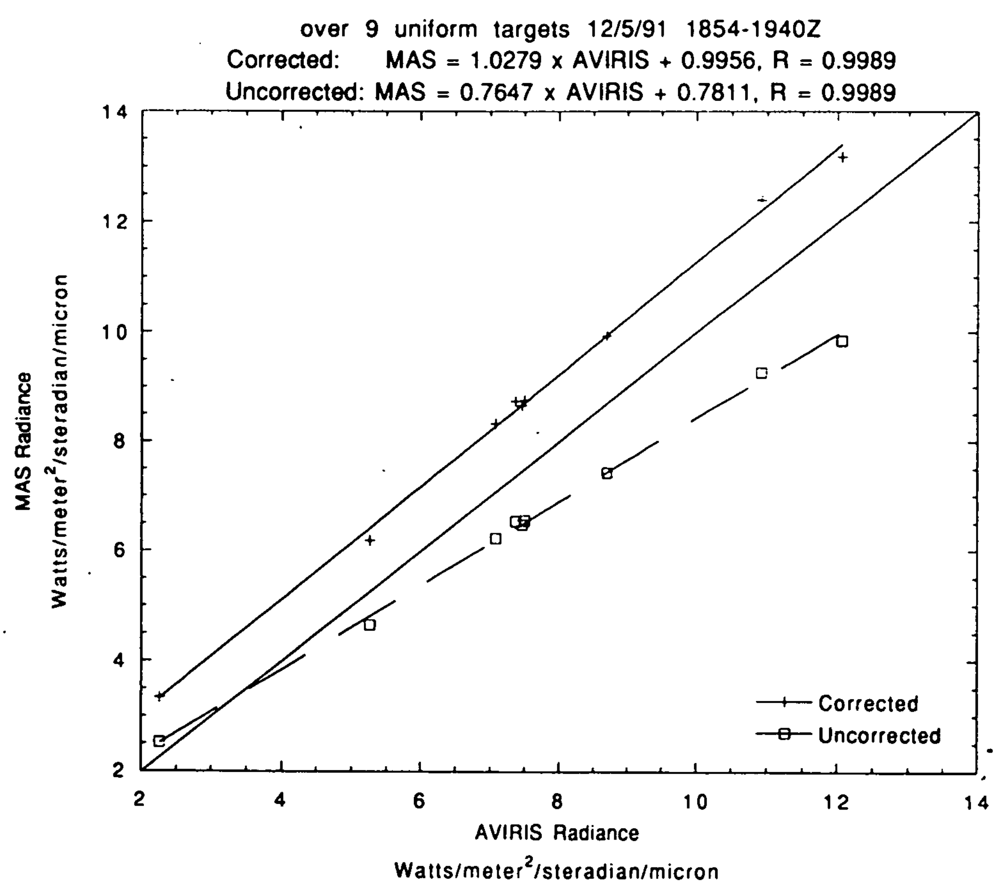
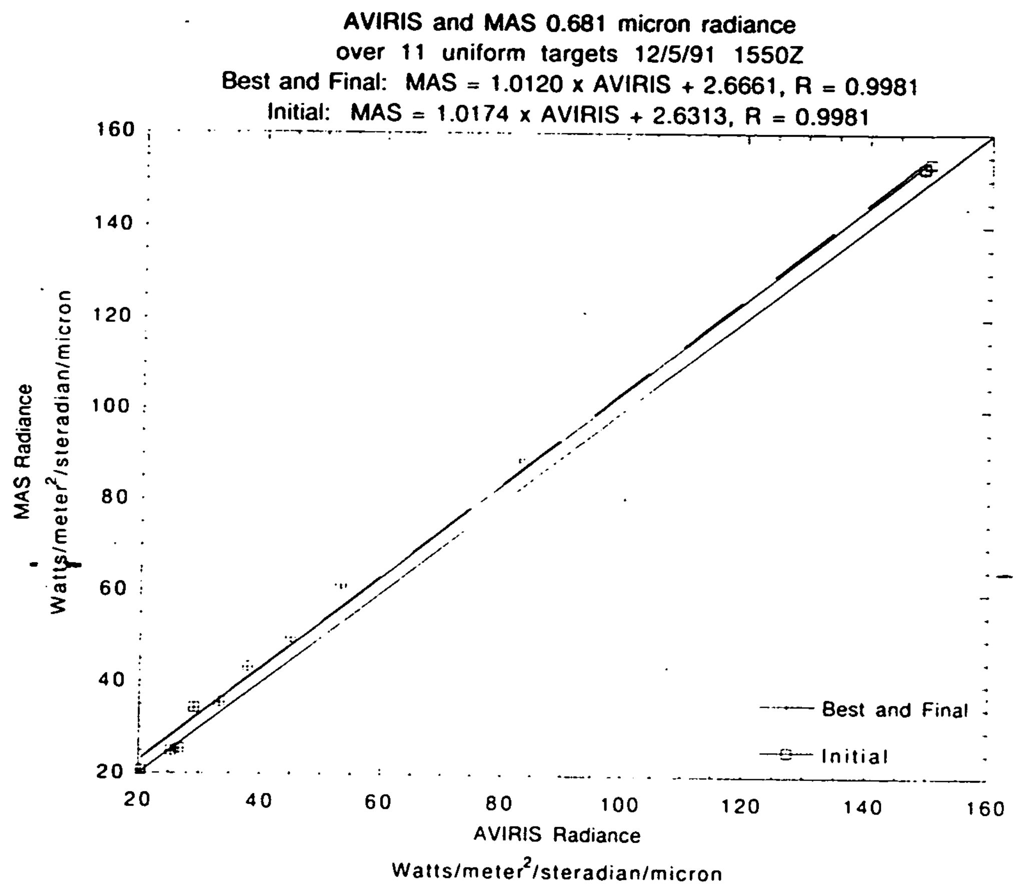

over 9 uniform targets 12/5/91 1854-1940Z
Corrected: MAS = 1.0279 x AVIRIS + 0.9956, R = 0.9989
Uncorrected: MAS = 0.7647 x AVIRIS + 0.7811, R = 0.9989
MAS Radiance
Watts/meter²/steradian/micron
AVIRIS Radiance
Watts/meter²/steradian/micron
Corrected
Uncorrected

Figure 3.


AVIRIS and MAS 0.681 micron radiance
over 11 uniform targets 12/5/91 1550Z
Best and Final: MAS = 1.0120 x AVIRIS + 2.6661, R = 0.9981
Initial: MAS = 1.0174 x AVIRIS + 2.6313, R = 0.9981
MAS Radiance
Watts/meter²/steradian/micron
160
140
120
100
80
60
40
20
20
40
60
80
100
120
140
160
AVIRIS Radiance
Watts/meter²/steradian/micron
Best and Final
Initial

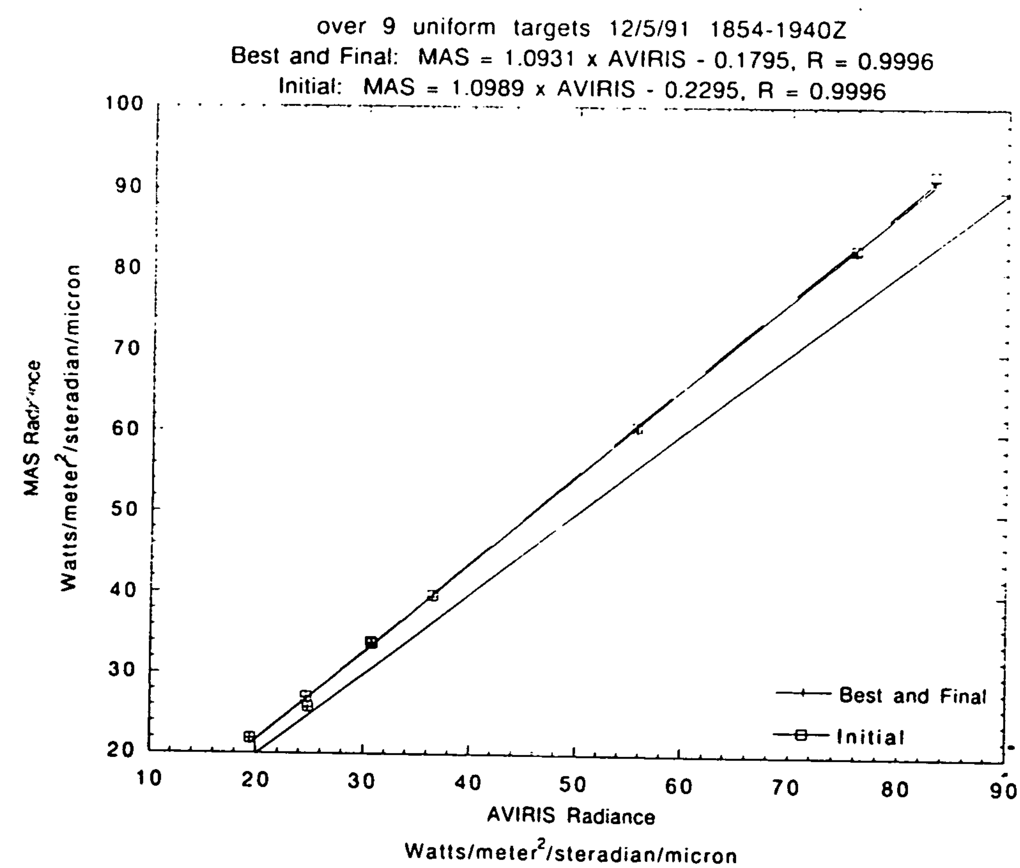
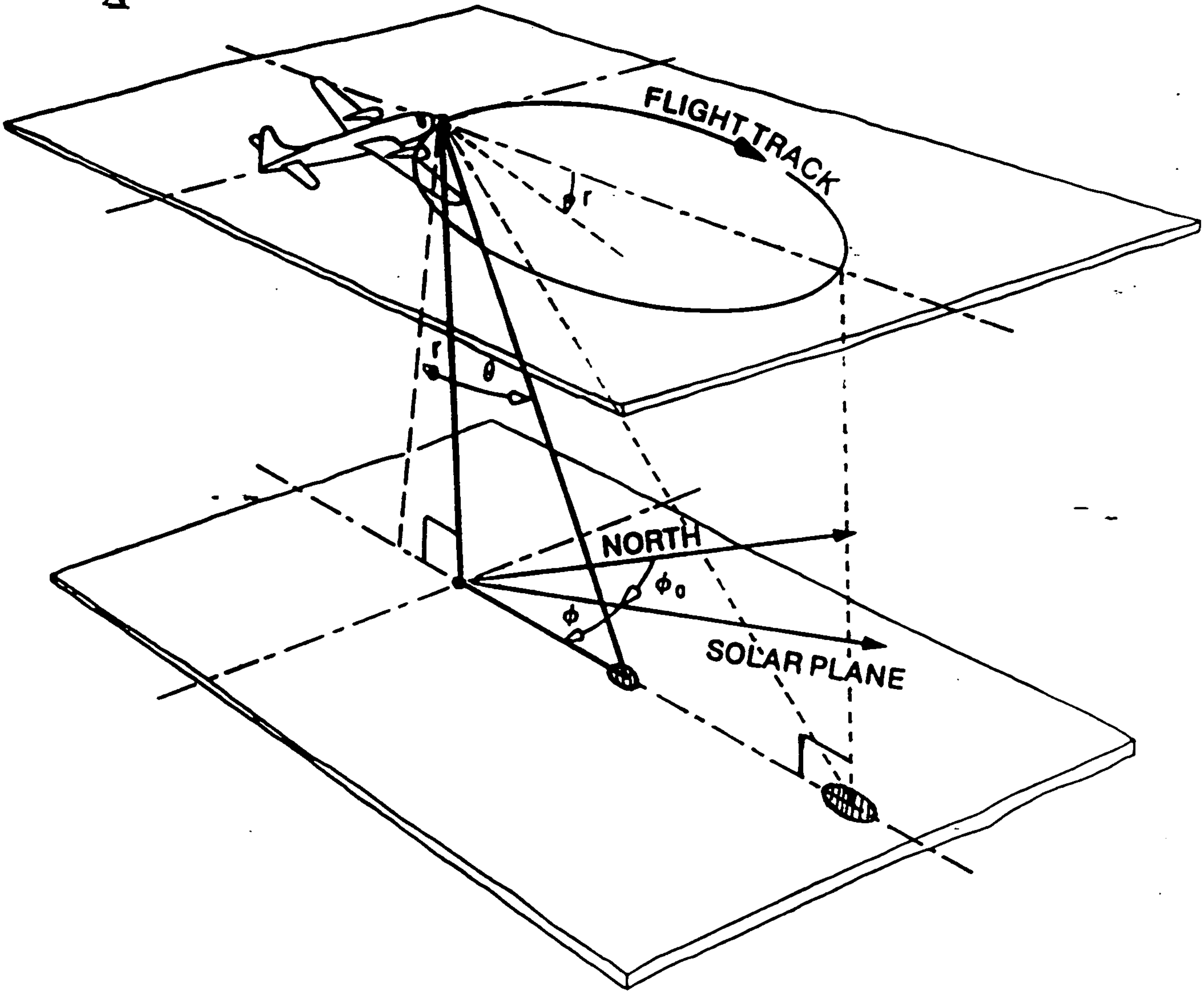

over 9 uniform targets 12/5/91 1854-1940Z
Best and Final: MAS = 1.0931 x AVIRIS - 0.1795, R = 0.9996
Initial: MAS = 1.0989 x AVIRIS - 0.2295, R = 0.9996
Watts/meter²/steradian/micron
100
90
80
70
60
50
40
30
20
10
20
30
40
50
60
70
80
90
AVIRIS Radiance
Watts/meter²/steradian/micron
Best and Final
Initial

Figure 4.

△ Specifications:



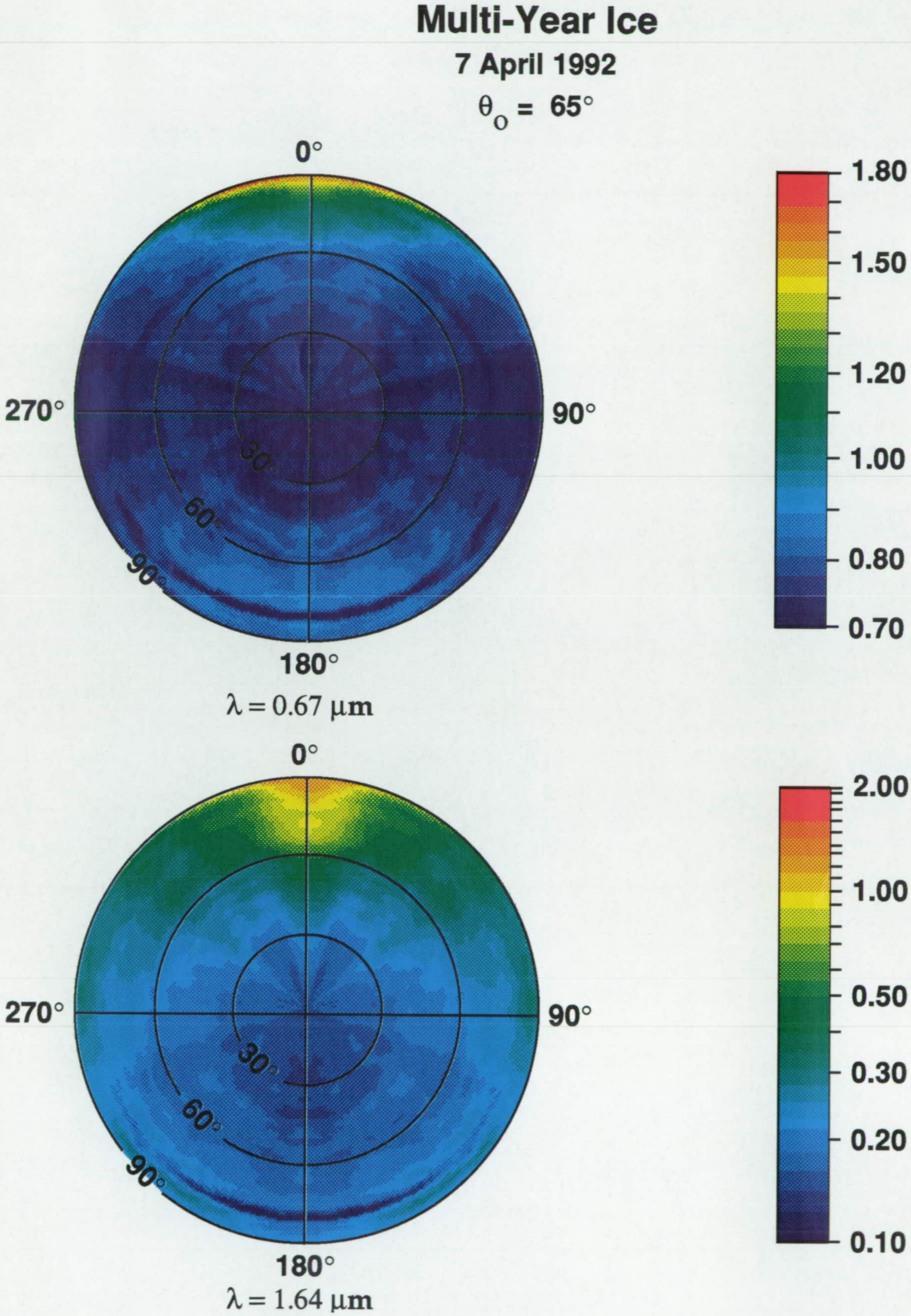
Instrumentation:

- ❑ Channels: 13
  7 continuously sampled;
  6 in filter wheel
- ❑ Field of view: 1°
- ❑ Spectral range: 0.3 - 2.3μm
- ❑ Aperture: ±95° about horizon
- ❑ Scan rate: 100 scans/min.
- ❑ Pixels in scan line: 395

Operation:

- ❑ Roll: ~20°
- ❑ Time: ~2 min.
- ❑ Speed: ~80 m.sec^{-1}
- ❑ Height: ~600 m
- ❑ Diameter: ~3 km
- ❑ Resolutions:
  ~10 m (nadir)
  ~270m (other end; θ, ~80°)

Figure 5.



Multi-Year Ice
7 April 1992
θo = 65°
0°
270°
90°
180°
30°
60°
90°
λ = 0.67 μm
1.80
1.50
1.20
1.00
0.80
0.70
0°
270°
90°
180°
30°
60°
90°
λ = 1.64 μm
2.00
1.00
0.50
0.30
0.20
0.10

Figure 6.

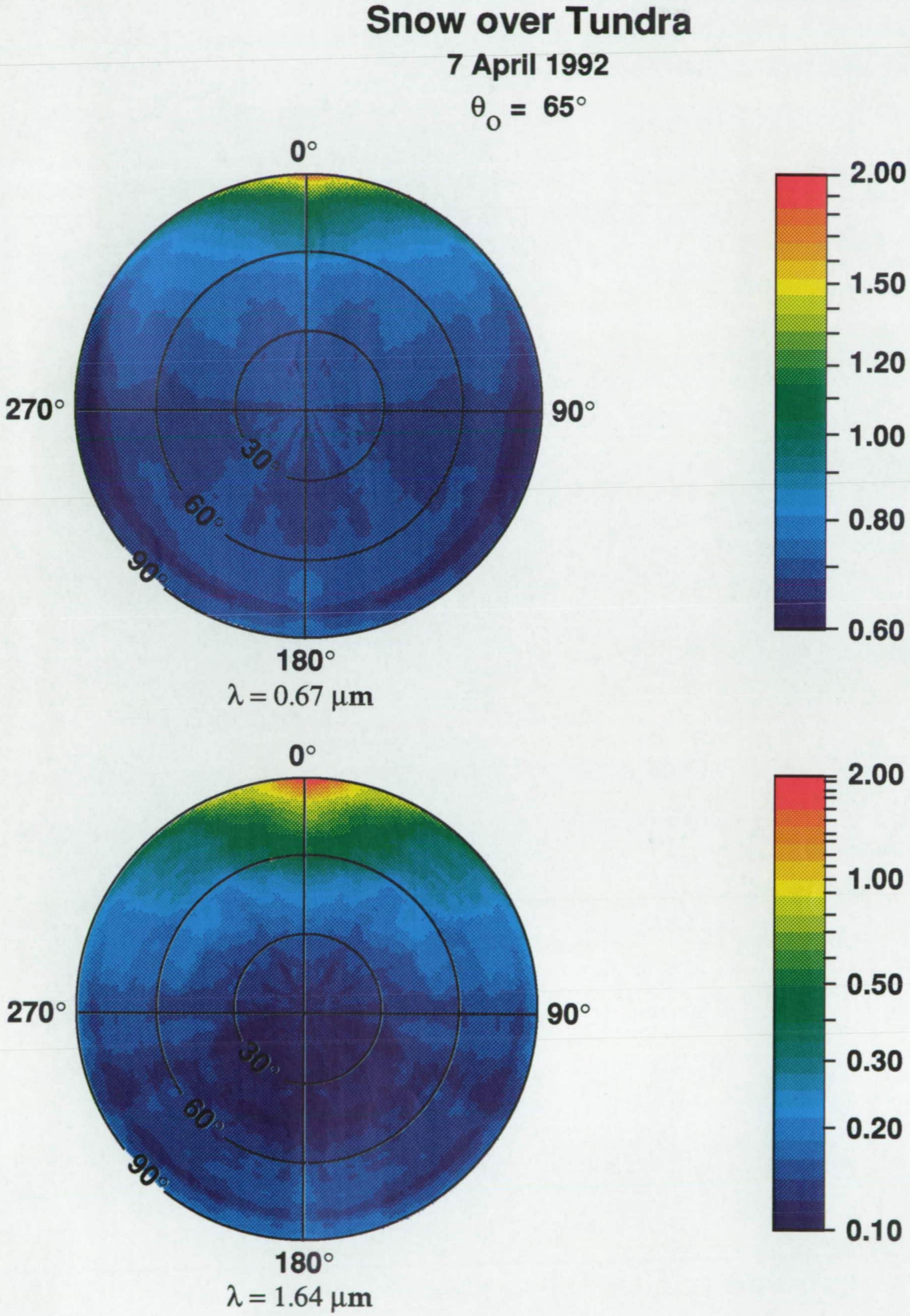

Snow over Tundra
7 April 1992
θo = 65°
0°
270°
90°
180°
30°
60°
90°
λ = 0.67 μm
2.00
1.50
1.20
1.00
0.80
0.60
0°
270°
90°
180°
30°
60°
90°
λ = 1.64 μm
2.00
1.00
0.50
0.30
0.20
0.10

Figure 7.

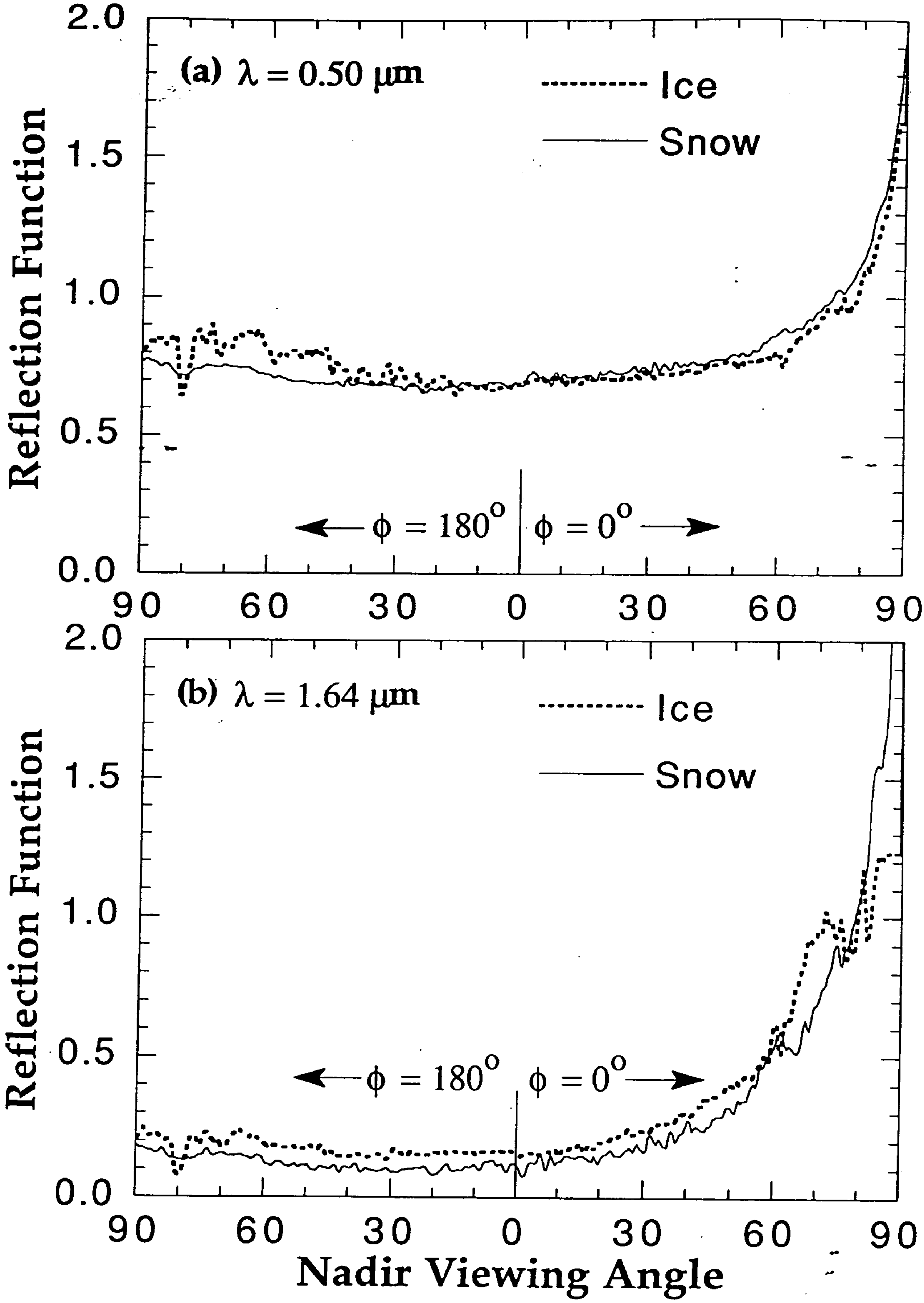

(a) λ = 0.50 μm
Ice
Snow
Reflection Function
φ = 180°
φ = 0°
2.0
1.5
1.0
0.5
0.0
90
60
30
0
30
60
90
(b) λ = 1.64 μm
Ice
Snow
Reflection Function
φ = 180°
φ = 0°
2.0
1.5
1.0
0.5
0.0
90
60
30
0
30
60
90
Nadir Viewing Angle

Figure 8.