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Abstract

Our major achievements of the past six months were: (i) the delivery of our MODIS Beta-3 cloud retrieval algorithm software for integration and testing; (ii) the creation of a Cloud Absorption Radiometer (CAR) operations manual and standardized data HDF format for the scientific community; (iii) the execution of a successful SCAR-B field campaign in Brazil with the MODIS Airborne Simulator (MAS) and CAR participation; (iv) revisions (with subsequent acceptance) of a MAS instrumentation paper to be published in the *Journal of Atmospheric and Oceanic Technology*; (v) completion of a new paper submitted for publication to the *Journal of the Atmospheric Sciences* on the sensitivity of inhomogeneous ice clouds to shortwave and longwave radiation at three MODIS wavelengths; (vi) submission of numerous abstracts to the 1996 International Radiation Symposium in Fairbanks (August 1996); and (vii) successful completion of the MAS calibration in Goddard's thermal/vacuum chamber.

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

The MODIS Beta-3 cloud retrieval algorithm has been completed and delivered to SDST by Menghua Wang for software integration and testing. Specifically, this delivery includes: (i) modification of the data input format for the cloud retrieval code made possible by creating an input file for easy input changes; (ii) modification of the solar zenith angle inputs from theta0(J) to theta0(I, J) for the Ith pixel and Jth scan line to accommodate the MODIS input data format; (iii) addition of cloud masking data input for each pixel - MASK(I, J) at the Ith pixel and Jth scan line [MASK(I, J) = 0 and 1 refer to cloudy and clear-sky pixels, respectively, for testing the flow of the cloud retrieval algorithm. The algorithm will be modified in coming months to use all cloud masking information (32 bit), e.g., to more properly assign cloudy or clear scene status]; and (iv) addition of subroutine ATM_CORRECTION for making atmospheric corrections. The MASDAT subroutine has also been changed accordingly. This cloud retrieval package that uses a MODIS synthetic data set in 'anchor' has also been tested. First, it was tested directly against the MODIS synthetic masking data set for all clear scenes. There are no cloud retrievals; however, the process flow has been tested. Then, reflectance values of synthetic data with real MAS data (cloudy) were re-assigned and run through the cloud retrieval process. A proper way of testing this algorithm is to convert MAS data to MODIS data format which is planned for completion soon.

In checking performance efficiency, it turns out that the cloud retrieval algorithm runs very slowly, with the most CPU time being spent on interpolation. For example, for one MODIS scan line of 1354 pixels, the cloud retrieval algorithm interpolates each pixel with a 3-point Lagrange scheme. Each pixel requires 10 interpolations (three-dimensional). In general, the reflected radiance is a smooth function of sensor viewing angle, and thus it may not be necessary to interpolate every pixel but rather every Nth pixel with a simple linear interpolation between them (one dimension instead of three). Thus, for MAS data (716 pixels/scan line), every 10th pixel (about every 1∞ of scan angle) was interpolated using a Lagrange scheme, and linearly interpolated between pixels. This modification increased efficiency by a factor of more than 2. For MODIS data, every 12th pixel (about 1∞ of scan angle) was interpolated, which cut the CPU requirements by a factor of more than 2. More sensitivity studies will be performed along this line.

In collaborating with the CERES science team, Steve Platnick finished working on atmospheric corrections for AVHRR and MAS data using the correlated k-distribution method for the 3.7 mm and thermal infrared channels, and MODTRAN for shorter wavelength channels. Several programmers from the CERES team at NASA Langley Research Center are interacting with him to integrate this cloud retrieval code into their global AVHRR testing.

b. MODIS-related Instrumental Research

Final calibration data for the Arctic Radiation Measurements in Column Atmosphere-surface System (ARMCAS, conducted in June 1995 over the Beaufort Sea, Alaska) and the Smoke, Clouds and Radiation–Brazil (SCAR-B, conducted in August-September 1995 in Brazil) are currently being prepared by Tom Arnold. The absolute calibrations measured by John Cooper for each spherical integrating source were used to calculate source radiance over MAS bandpasses for processing all lamp levels at one time. These radiance values for each lamp level and each MAS band were combined with MAS count values from which radiance per count was computed. Such a procedure was followed for the two ARMCAS calibrations as well. These data will be compared to 30-inch Ames integrating sphere calibrations. During SCAR-B, three separate MAS calibrations were conducted with the MAS elevated above a 20-inch integrating hemisphere shipped to Brasilia. Tom Arnold and Mike Fitzgerald (Ames Research Center) have worked on comparison of these data to those of ARMCAS pre-flight data, as well as in-flight data in Alaska. We observed that bad data occurred occasionally (at very warm temperatures) in MAS bands 10, 16, 19, and 20.

We conducted MAS calibrations in the GSFC thermal vacuum chamber from 27 November - 8 December 1995. These tests will assist in determining the final calibration coefficients for the visible and near-infrared channels of MAS. First, the source stability in the thermal vacuum chamber was tested by John Cooper and Danny Lester. They concluded that the calibration source should be set up outside the chamber. Then, the MAS was set up in the chamber with insulating covers removed and heaters turned off. A total of nine tests were conducted by Tom Arnold and Steve Platnick (with the help of Pat Grant and Pavel Hajek from NASA/Ames). where only four lamps were used for the source intensity to effectively eliminate saturation in the port 2 bands (especially bands 10-14). Test 1 consisted of the thermal vacuum chamber being held at room temperature while the pressure was reduced three times, backfilling to ambient pressure with liquid N_2 between pressure reductions, with data being recorded both during and at the end of each transition. Test 2 consisted of repeating test 1, except after the 3rd pressure reduction the chamber was held at low pressure while the temperature was further reduced. MAS cooled to about -30∞ C (which took about 10 hours), data being recorded periodically as the chamber was cooling. Test 3 repeated test 2. Test 4 consisted of starting at ambient temperature and pressure, but warming up the MAS via internal heaters to nearly +40∞ C. Test 5 consisted of keeping the insulating cover on, silicon cooler added, and initially heaters off, as the chamber air pressure was reduced to 40 mm Hg and twice backfilled with liquid N_2. Following the 3rd pressure reduction, pressure was held constant and temperature was reduced. When MAS reached about -3∞ C, the heaters were turned on, wherein the instrument temperature rapidly increased to +10∞. MAS was then allowed to cool to -15∞. Heaters were turned on once again but the temperature still would not stabilize. The instrument then was allowed to warm naturally and a few more data points were obtained. Test 6 involved removing the insulating cover prior to the test because only a short period of time was available for the test. With the source already on and stable, we turned the MAS on and data were recorded immediately to compare with data taken 15 and 30 min later to see how the MAS counts might change during warm up. Test 7 started at ambient temperature and pressure while the MAS was warmed up by heatingthe entire chamber to about +30∞ C. Test 8 consisted of keeping the insulating cover on while pressure was cycled (as in test 5), after which point the MAS was cooled to -30∞ C. Test 9, which began at reduced pressure, involved turning the heaters on to warm the MAS in small increments. Data were taken frequently. The repeatability of the MAS radiometric characteristics and its variation with instrument temperature and pressure are currently under careful investigation.

Returning from ARMCAS, the CAR was set up in the Code 925 calibration lab and full calibrations were conducted using both the Goddard 6-foot integrating sphere and 48-inch integrating hemisphere. Preliminary analysis of these data showed that calibration was successful. Then, the CAR was shipped back to the University of Washington for participation of the SCAR-B campaign. During part of SCAR-B, the CAR was rotated 90∞, scanning from horizon to horizon, to serve as an imager for the first time. It was very successful. However, due to an engine failure by the C-131A before returning to the US, the CAR has only recently been shipped back to Goddard for post-flight calibration.

c. SCAR-B experiment

The SCAR-B (Smoke, Clouds, and Radiation–Brazil) was conducted successfully in Brazil from 16 August to 14 September 1995 as part of the MODIS atmospheric science team activity. Michael King, Tom Arnold, Jason Li and Si-Chee Tsay participated in most of the SCAR-B operation and observational activities during this period. The MAS flew onboard the NASA ER-2 aircraft while the CAR flew onboard the University of Washington's C-131A aircraft. Both of these instruments performed well, acquiring valuable data sets of the radiative properties of smoke, clouds, fire, and various surfaces. These data sets are currently being processed and will be available for all scientists involved to study the effects of biomass burning on atmospheric processes and remote sensing. Preliminary MAS data acquired on 18 August 1995 were processed and presented to NASA HQ by Dr. R. Curran.

d. MODIS-related Services

1. Meetings

1. Steve Platnick attended the ONR/MAST science team meeting in London on 24-28 July 1995 and presented results analyzed from the ER-2 MAS dataset on ship tracks;

2. Menghua Wang attended the MODIS calibration support team workshop on 9 August 1995 at NASA Wallops Flight Facility and presented results from a study of atmospheric correction algorithms for ocean color sensors;

3. Si-Chee Tsay attended the Code 900 Monthly Technical Review on 11 August 1995 and presented a study of the effects of cloud inhomogeneity on atmospheric energetics and remote sensing using three MODIS channels;

4. Michael King gave presentations both to the press and to cabinet ministers in Brasilia at the mid-point of the SCAR-B experiment;

5. Michael King attended the CERES science team meeting at NASA Langley Research Center on 20-22 September 1995 and presented an update on EOS as well as preliminary results acquired during the ARMCAS and SCAR-B cam-

paigns;

6. Michael King attended the National Research Council review of the US Global Change Research Program, with an emphasis on NASA's Mission to Planet Earth/EOS. He discussed NASA's plans for data validation with V. Ramanathan, Jerry Mahlman, and Ed Frieman, among others.

7. Michael King, Tom Arnold, Steve Platnick, and Si-Chee Tsay attended the Airborne Sensors Workshop on 3-4 October 1995 at NASA Goddard to discuss the development of at least two new airborne instruments in support of EOS and other MTPE science objectives.

8. Michael King participated in a FIRE III Arctic Stratus Drafting Panel meeting on 16-18 October 1995 in Ft. Collins, CO. The purpose of this workshop was to write a FIRE III implementation plan for an arctic stratus experiment, an excellent opportunity to validate EOS AM-1, and especially MODIS and CERES, data products over arctic stratus clouds and sea ice in polar regions during the summer.

9. Michael King and Si-Chee Tsay attended the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) planning meeting on 1-3 November 1995 in Columbia, MD to discuss the science and implementation plan.

10. Michael King attended the Tropospheric Chemistry and Aerosol Workshop at Goddard Institute for Space Studies in New York on 6-9 November 1995. He gave a presentation describing the capabilities of MODIS and MISR for deriving atmospheric aerosol properties from EOS AM-1, and participated in writing the workshop report on indirect effects of aerosols on clouds and hence climate.

11. Michael King, Steve Platnick, Si-Chee Tsay and Menghua Wang attended the MODIS science team meeting on 15-17 November 1995 at NASA Goddard, which focused primarily on validation plans for the Atmosphere Group as a whole.

12 Michael King attended the EOS Payload Panel Meeting on 28-30 November 1995 in Annapolis, MD. This meeting focused on NASA's response to the NRC Review of EOS, including EOSDIS, tropospheric chemistry and aerosols, and new technology insertion opportunities of the future.

2. Seminars

1. Michael King gave a seminar entitled "Biomass Burning and Remote Sensing in Brazil," while at Colorado College on 4 September to receive an honorary Doctor of Science degree.

2. Michael King gave a seminar at the National Center for Atmospheric Research on 6 September, entitled "Clouds, Radiation and Climate from EOS."

III. Data/Analysis/Interpretation

a. Data Processing

The MAS 50-channel Level-1B processing software has been completed by Paul Hubanks. Additional metadata parameters, including analog gain and offset, MAS clock time (which had to be aligned with the GPS navigation data), and Head1/2 counts and temperatures, are now stored in HDF output. The blackbody count changes (due to DC drift) in the visible and near-infrared channels have been compensated and those of the infrared channels in port 3 and 4 (due to a "saw-tooth effect" in the new digitizer) are currently under developing by the Ames Data Facility. Some of the Level-0 data from the Snow/Ice Mapping Mission (April, Alaska) and ARMCAS (June, Alaska) campaigns were processed through the Level-1B software system to create browse imagery. These test browse images of MAS 50-channel data have been included in the Browse Imagery Archive in the MAS World Wide Web site.

One of MAS 50-channel data flight lines acquired on 13 June 1995 during ARMCAS was processed and resampled to see how well the MAS performed in the arctic environment, characterized by high reflectance snow and sea ice surfaces with rapid small-scale variations in open leads, melt and refrozen ponds, and arctic stratus clouds. Figure 1 shows a MAS visible (0.657mm) image of low-level stratus clouds over arctic sea ice and snow (Beaufort Sea, Alaska). The image covers a total domain size of 37 by 23 km and shows rich features of the arctic sea ice that forms a valuable data set for cloud mask and cloud property retrievals. In addition, four interesting scenes acquired on 18 August 1995 during SCAR-B were identified to see how well the MAS was suited to the monitoring of aerosol and surface properties from space. Figure 2 shows a MAS RGB (2.129, 0.869, 0.657 mm, respectively) composite image over a large area of cerrado (northwest of Brasilia, Brazil) and covers a total domain size of 37 by 40 km. Various types of surface vegetation are surrounded by two rivers with bare sand islands (bright reflectance). Numerous large black spots were caused by recent biomass burning. A striking feature observed in this image is the large area (bluish) covered by smoke and aerosols that is produced by two fires (red flame front) located on the left side of the image. We believe that this pattern of fire characterizes a prescribed light-grassland (cerrado) fire progressing only at the edge of the burning area. Figure 3 shows a dramatic image of so-called "fumulus" clouds that appear like clouds but are actually composed of ash with no water content at all. The large area of biomass burning produced strong convective activity and brought all kinds of aerosols and particles into the atmosphere. A large fire is clearly visible in the 2.129 mm channel (red). Large areas were also covered by smoke aerosols (blue) and cloud shadows (black).

All CAR data are now stored on 8 mm Exabyte tapes. Jason Li has processed selected CAR data obtained during the Kuwait Oil Fire (May 1991), FIRE I marine stratocumulus (July 19876), and Monterey Area Ship Tracks (June 1992) experiments into HDF format. This standard format will be easier to use in analyzing diffusion domain data and surface bidirectional reflectance. Figure 4 shows the bidirectional reflectance distribution function, using data obtained during the Kuwait oil fire experiment. Many IDL routines have been developed to compute and display BRDF in a 3-D space using the standard color bar used by oceanographers. These sets of tools will be used in the near future for analyzing CAR data sets. Figure 5 shows about 40 minutes of data (RGB imagery of 0.87, 0.67, 0.47 mm, respectively) acquired during SCAR-B, when the CAR was rotated 90∞, permitting it to scan from horizon to horizon. This is the first time that CAR has been used as a horizon to horizon imager. Since the aerodynamics of the C-131A is far more complicated than the ER-2, we are currently working on geometry correction routines for analyzing these data.

A CAR Operator's Manual was prepared to assist scientists flying or preparing to fly with the CAR onboard the University of Washington aircraft. This document, which was compiled, edited, and completed by Ward Meyer, describes the CAR instrument, operation, and scientific objectives, and presents selected results to illustrate details of the application of this sensor to varying operating conditions. We plan to create a CAR home page on World Wide Web to enable a much wider communication to users of these datasets.

b. Analysis and Interpretation

We have completed a sensitivity study using three MODIS spectral channels (1.38, 1.64, and 11 mm) to explore the effects exerted by uncertainties in cloud microphysics (e.g., particle size distribution) and cloud inhomogeneity on the apparent radiative properties, such as spectral reflectance and heating and cooling rate profiles of cirrus-like clouds. Results of this study suggest that: (i) while microphysical variations in the scattering and extinction functions of clouds affect the magnitudes of their spectral reflectances, cloud morphology significantly alters the shape of their angular distribution, (ii) spectral reflectances viewed near nadir are the least affected by cloud variability, and (iii) cloud morphology can lead to spectral heating and cooling rate profiles that differ substantially from their plane-parallel averaged equivalents. Since there are no horizontal thermal gradients in plane-parallel clouds, it may be difficult to correct for this deficiency. A paper entitled "Spectral reflectance and atmospheric energetics in cirrus-like clouds. Part II: Applications of a Fourier-Riccati approach to radiative transfer" has been submitted to the *Journal of the Atmospheric Sciences* for publication.

Simulations of CAR measurements using both discrete-ordinate (DisORT) and Monte Carlo radiative transfer codes were conducted by Robert Pincus to investigate: (i) what portion of a cloud appears to be in the diffusion domain (a function of azimuth angle), and (ii) to what extent the interpretation of CAR measurements is sensitive to, for example, the specification of single-scattering phase function. In collaborating with Alexander Marshak, Pincus has also examined how the internal radiation field in inhomogeneous clouds differs from the radiation field in homogeneous clouds. For example, by comparing the angular distribution of radiance as a function of optical depth, at some levels the homogenous cloud appeared to be in the diffusion domain (according to the CAR algorithm) but the Monte Carlo results always failed.

IV. Anticipated Future Actions

a. Continue to analyze MAS calibration data acquired from the GSFC thermal vacuum chamber in November-December and suggest the best strategy for future radiometric calibration;

b. Continue to analyze MAS data obtained from the MAST field campaign and compare with in situ microphysics measurements;

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 I;

f. Attend FIRE-III and SCAR-B Science Team meetings in Williamsburg, VA (February 14-16, 1996) and GSFC (March 21-22, 1996), respectively.

g. Prepare and conduct the SUCCESS field campaign in Kansas to acquire MAS, HIS, and CLS data in April 8 - May 10, 1996.

V. Problems/Corrective Actions

No problems that we are aware of at this time.

VI. Publications

1. King, M. D., D. D. Herring and D. J. Diner, 1995: The Earth Observing System (EOS): A space-based program for assessing mankind's impact on the global environment. *Opt. Photon. News*, **6**, 34–39.

2. Gumley, L. E., and M. D. King, 1995: Remote sensing of flooding in the

US upper midwest during the summer of 1993. *Bull. Amer. Meteor. Soc.*, **76**, 933–943.

3. King, M. D., S. C. Tsay and S. Platnick, 1995: In situ observations of the indirect effects of aerosol on clouds. *Aerosol Forcing of Climate*, R. J. Charlson and J. Heintzenberg, Eds., John Wiley and Sons, 227–248.

4. Schwartz, S. E., F. Arnold, J. P. Blanchet, P. A. Durkee, D. J. Hofmann, W. A. Hoppel, M. D. King, A. A. Lacis, T. Nakajima, J. A. Ogren and O. B. Toon, 1995: Group report: Connections between aerosol properties and forcing of climate. *Aerosol Forcing of Climate*, R. J. Charlson and J. Heintzenberg, Eds., John Wiley and Sons, 251–280.

5. Platnick, S., and F. J. P. Valero, 1995: A validation of a satellite cloud retrieval during ASTEX. *J. Atmos. Sci.*, **52**, 2985–3001.

6. King, M. D., and M. K. Hobish, 1995: Satellite instrumentation and imagery. *Encyclopedia of Climate and Weather*, Oxford University Press (in press).

7. Wielicki, B. A., R. D. Cess, M. D. King, D. A. Randall and E. F. Harrison, 1995: Mission to Planet Earth: Role of clouds and radiation in climate. *Bull. Amer. Meteor. Soc.*, **76**, 2125–2153.

8. Tsay, S. C., M. D. King and P. V. Hobbs, 1995: Arctic radiation measurements in column atmosphere-surface system - Science Plan. NASA GSFC internal report.

9. 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*. in press.

10. 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. Submitted to *J. Atmos. Sci*.

11. Platnick, S., P. Abel and M. D. King, 1996: The effect of water vapor absorption on integrating sphere output radiance and consequences for instrument calibration. Presented at the *Conference on NASA's Earth Observing System*, SPIE, Denver, CO.

12. Arnold, G. T. , M. Fitzgerald, P. S. Grant, and S. E. Platnick, S. C. Tsay, J. S. Myers, M. D. King, R. O. Green and L. Remer, 1996: Radiometric calibration of the MODIS Airborne Simulator (MAS). Presented at the *Conference on NASA's Earth Observing System*, SPIE, Denver, CO.

13. King, M. D., S. C. Tsay and P. V. Hobbs, 1996: Arctic Radiation Measure-

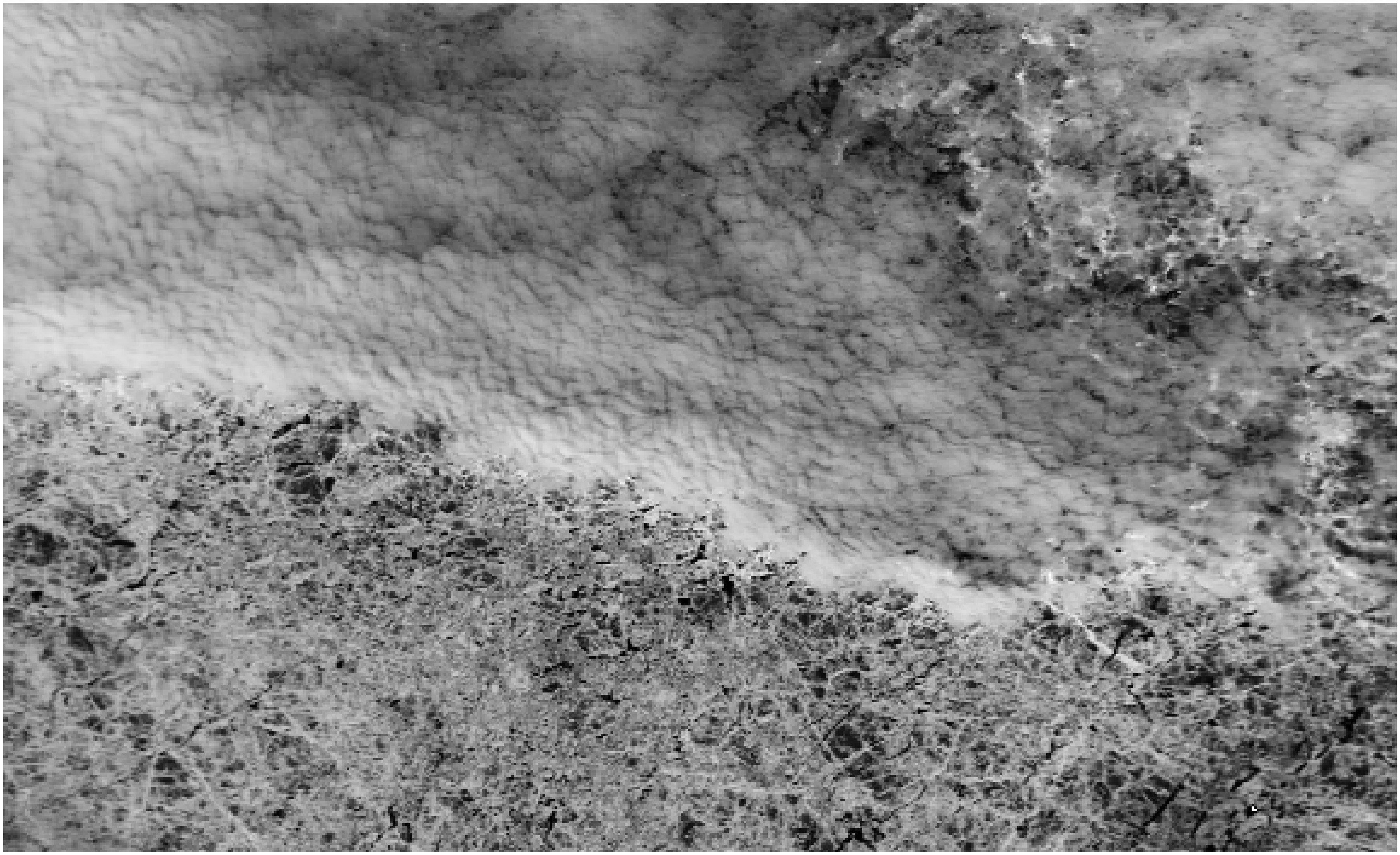
ments in Column Atmosphere-surface System. Presented at the *International Radiation Symposium*, Fairbanks, AK.

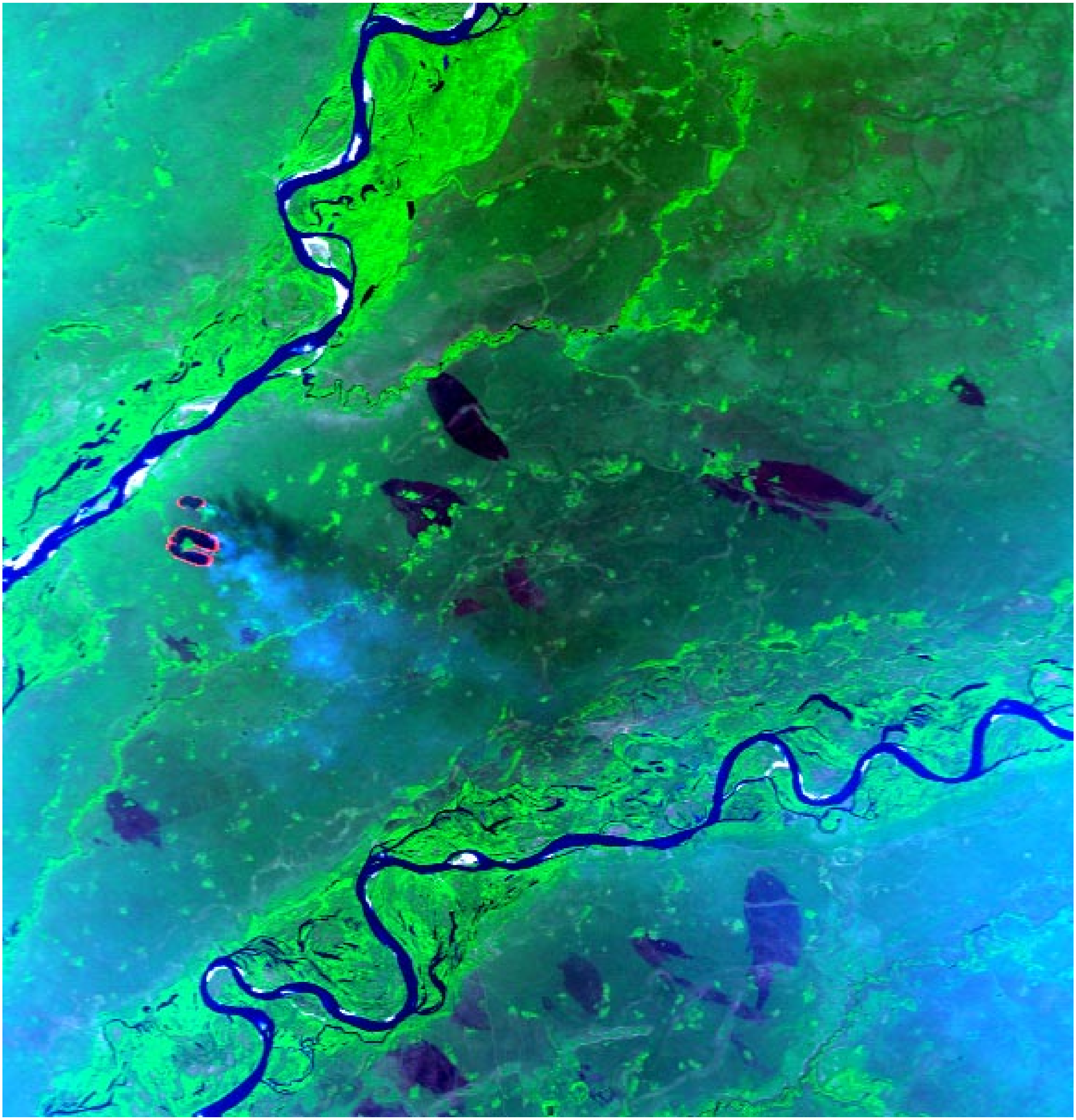
14. Pincus, R., M. D. King and S. C. Tsay, 1996: In situ measurements of the absorption of solar radiation in stratiform water clouds. Presented at the *International Radiation Symposium*, Fairbanks, AK.

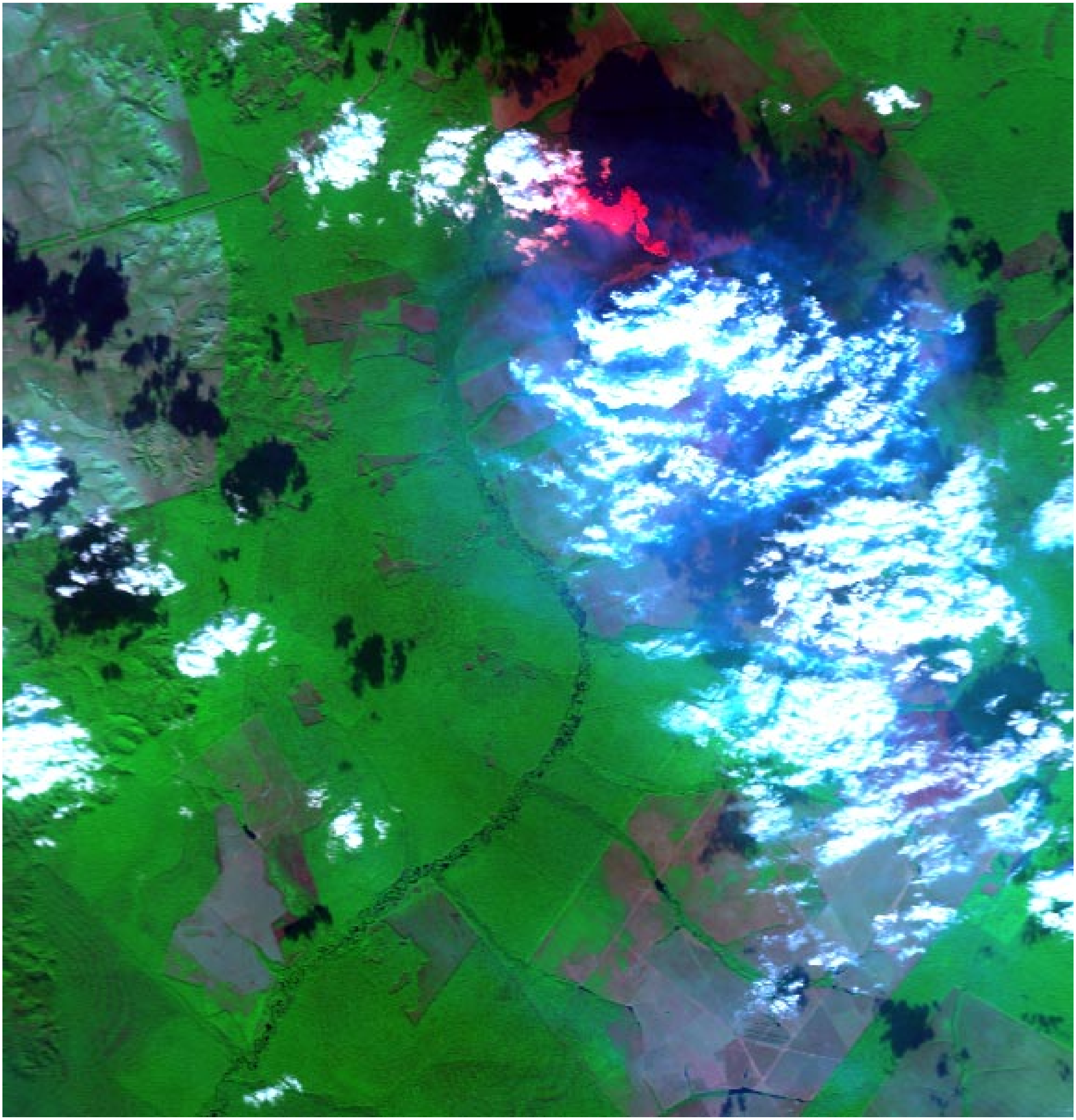
15. Pincus, R., A. Marshak, A. Davis, M. D. King and W. J. Wiscombe, 1996: Diffusion domain retrievals of single scattering albedo inside thick but variable clouds. Presented at the *International Radiation Symposium*, Fairbanks, AK.

16. Wang, M., and M. D. King, 1996: Rayleigh scattering effects on cloud optical thickness retrievals. Presented at the *International Radiation Symposium*, Fairbanks, AK.

17. Platnick, S., and M. D. King, 1996: Impact of cloud inhomogeneity on the retrieval of cloud radiative and microphysical properties. Presented at the *International Radiation Symposium*, Fairbanks, AK.







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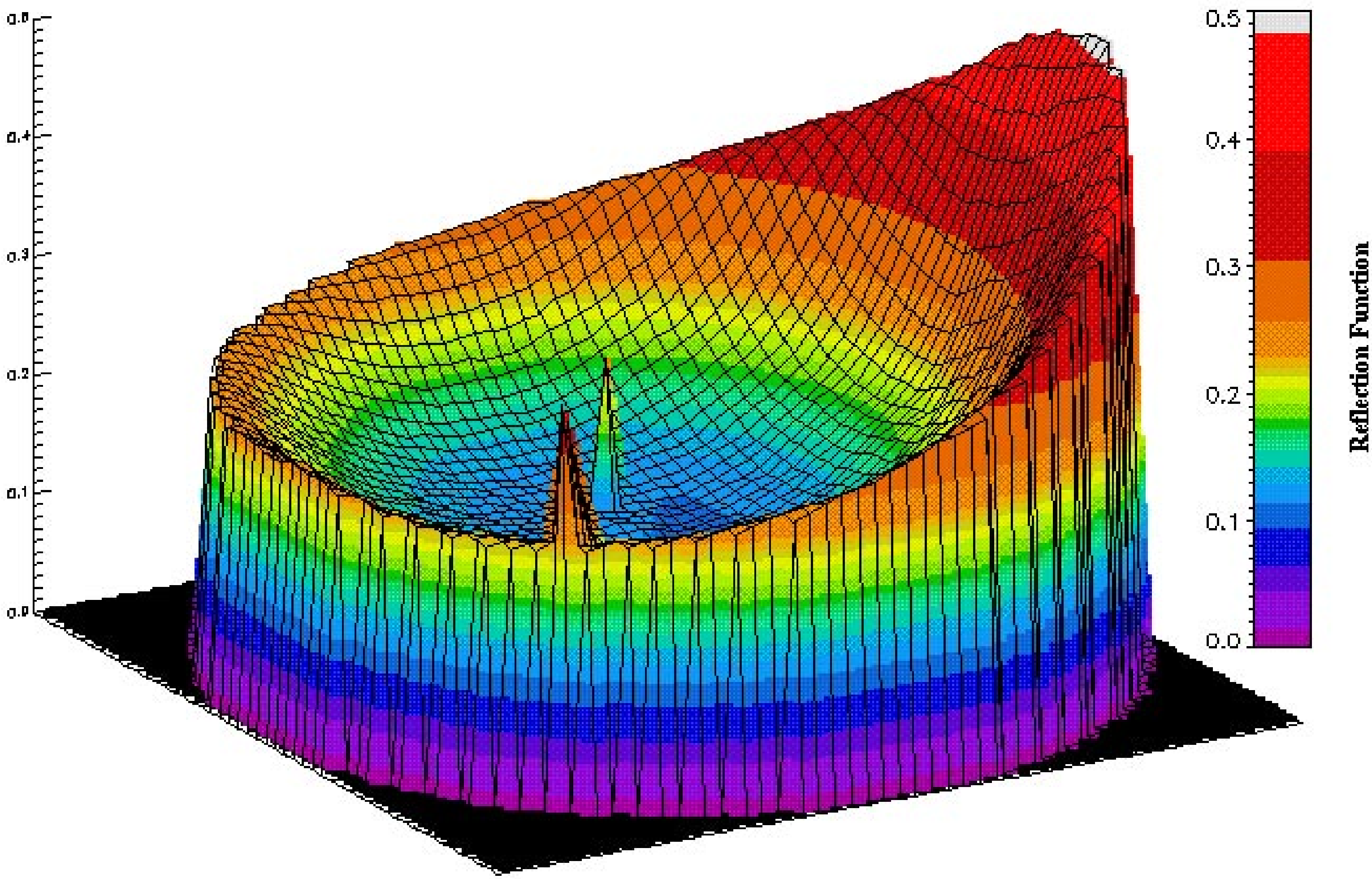

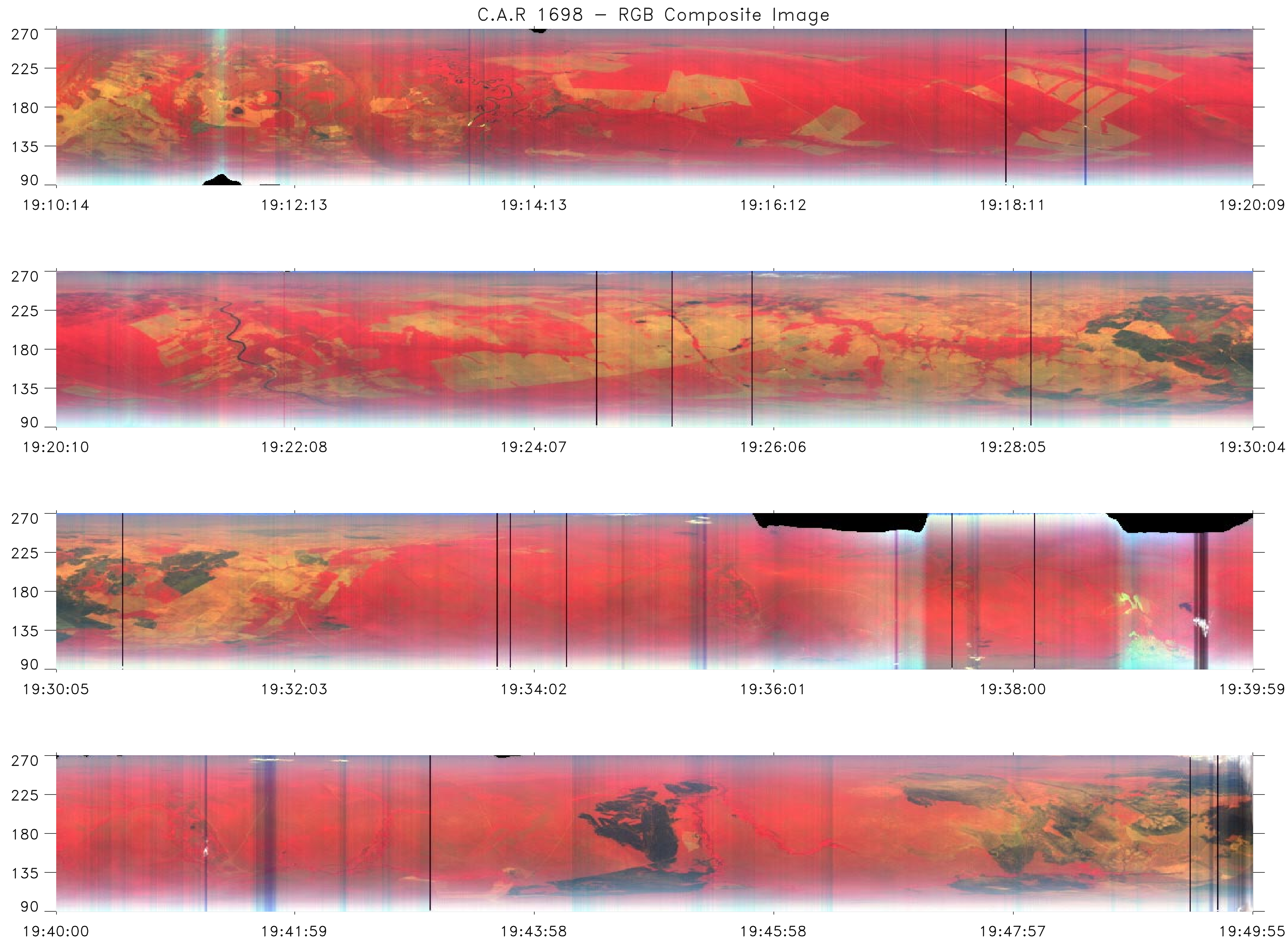
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