MODIS Semi-annual Report
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Abstract

Major efforts over the past six months included: (i) continued development and refinement of MODIS level 2 and 3 (L2, L3) visualization software for use by the atmosphere group, (ii) analysis of the MODIS L2 cloud retrieval algorithm and ancillary data sources for selected granules, (iii) modifications to the L2 code based on granule level analysis, (iv) participation in the SAFARI 2000 dry season campaign in southern Africa, and subsequent data analysis, and (v) continued analysis of MAS and CAR data from the arctic FIRE-ACE experiment.

I. Task Objectives

With the use of related airborne instrumentation, such as the MODIS Airborne Simulator (MAS) and Cloud Absorption Radiometer (CAR), our primary objective is to extend and expand algorithms for retrieving the optical thickness, effective radius, and water path of liquid and ice clouds using radiation measurements 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 Data Analysis, Code and Related Software Development

MOD06 Level-2 cloud retrieval code

Mark Gray, Eric Moody, Steven Platnick, and Michael King have examined MODIS Level 2 cloud optical thickness and effective radius retrievals. Examination of various liquid water cloud scenes gives results physically realistic and consistent with our understanding of these systems. Ice cloud retrievals also appear consistent with reported in situ measurements.

Three separate cloud particle size retrievals are derived by the code (using the 1.6, 2.1, and 3.7 μm bands). The relative value of the size retrieval among the three bands in single layer water clouds has been theoretically examined, as well as empirically determined with MAS retrievals. The three MODIS retrievals are being evaluated for marine stratocumulus clouds. Initial results show a larger difference than expected between the bands.

Examples of L1B saturation have been found in band 2 and 5 (0.86 and 1.24 µm, respectively) over cloud scenes. A document showing examples of this saturation, as well as examples of SWIR band striping and alternate sampling differences, has been given to MCST. Resolution of these L1B issues is critical to the success of the cloud retrieval science product.

Some modifications to the code have been implemented by Mark Gray. Eric Moody modified several Quality Assurance/Assessment flags, categories, and assignments. As part of the analysis effort, Eric Moody developed a number of tools for visualization of cloud mask tests, L2 SDS's, and ancillary data sets. Jason Li replaced the current 10 km IGBP ecosystem map used in the retrieval code with a 1 km version, including the addition of a tundra ecosystem adapted from the 10 km map (see **Fig. 1**). The ecosystem map is used as a surrogate for the assignment of spectral surface albedo.

Tom Arnold and Ping Yang have been working with the cloud reflectance libraries. Arnold developed software for plotting the libraries in the retrieval reflectance space, providing a visual indication of retrievals and their sensitivity. As a consequence, he has also investigated the asymptotic parameter libraries. The plotting tool will be used in a paper summarizing Arctic cloud retrievals during FIRE-ACE. Ping Yang has recomputed the water and ice reflectance libraries. The water library comparisons are in excellent agreement with the original MODIS library; ice library comparisons are ongoing.

The cloud retrieval code, a part of MOD06 L2 data set, was released on 29 September 2000, with the data set starting on 20 August.

MOD08 Level-3 atmosphere code

Using the recently developed MOD08 browse system, several MOD08 software bugs were noted. The major bug was in the MOD08 Eight-Day and Monthly production code where multi-day data were not combined correctly. Paul Hubanks made corrections to the code and redelivered them to SDST (and later integrated them into MODIS production (MODAPS)). Also noted and corrected was a MOD08 Tiling Code bug that caused the incorrect computation of QA-weighted standard deviation. The tiling code was corrected and redelivered to SDST, and the fix has now been integrated into MODIS production (MODAPS). Hubanks has also examined the reason for the unintended population of Cloud_Fraction_SWIR SDS's in MOD08. By using bit-visualization tools to peruse the contents of L2 HDF files, it has been concluded that this problem is a code bug in the L3 tiling software.

Paul Hubanks has begun working on correcting and/or updating the MOD08 (MODIS Atmosphere Joint Product) Tile, Daily, Eight-Day, and Monthly CDL file specs and corresponding HDF structure files. The following changes are in the process of being implemented: a) For consistency with the latest L2 "Processing Path QA," L3 "Undetermined" SDS's will be added, along with "Mixed

Phase," for Cloud Optical Thickness, Cloud Effective Radius, Cloud Fraction and Water Path parameter groups. b) "Combined" (Combined Phase) SDS's will be added for Cloud Optical Thickness, Cloud Effective Radius, Cloud Fraction and Water Path parameter groups. c) The local attribute "units" will be corrected (changed from "mm" to "cm") on all Atmospheric Water Vapor SDS's. d) Numerous "valid_range" local attributes will be modified to sync with L2. e) Several "scale_factor" local attributes will be modified to match recent L2 modifications.

Eric Moody was involved in porting his high resolution L3 code (0.1°) into MODAPS production. Though run in production, the high resolution output will not be an official product but will be pushed to local machines without DAAC archiving. Production of the code is expected to begin in February 2001.

MODIS Atmosphere web site development

Paul Hubanks worked on the following MODIS Atmosphere web site items:

1. Browse images (see **Fig. 2** for example):

   MOD08 Daily Product: Continued work on generating and uploading to the MODIS Atmosphere web site, a complete set of browse images (over 500 images per day) for each MOD08_D3 (MOD08 Daily Global) product file. This work has continued on a daily basis.

   MOD08 Eight-Day Product: Completed development of a web-based browse system for the MOD08 Eight-Day Product. Continued work on generating and uploading to the MODIS Atmosphere web site, a complete set of browse images (over 500 images per day) for each MOD08_E3 (MOD08 Eight-Daily Global) product file. This work has continued on an eight-day basis.

   MOD08 Monthly Product: Completed development of a web-based browse system for the MOD08 Monthly Product. Continued work on generating and uploading to the MODIS Atmosphere web site, a complete set of browse images (over 500 images per day) for each MOD08_M3 (MOD08 Monthly Global) product file. This work has continued on a monthly basis.

2. Fixed (Optimized) Scale Browse Image generation and display scripts: Completed the development of fixed (optimized) scale IDL scripts to generate browse images for the MOD08 Daily, Eight-Day and Monthly products. The scale was manually selected and specified for each of the many hundreds of SDS's in each product. Interaction with each L2 development team was necessary to optimize the selected scale. Fixed-scale browse replaced the previously displayed variable-scale browse on the MODIS Atmosphere web site.

3. Updated the Publications section of the MODIS Atmosphere web site with new versions of papers published by the MODIS Atmosphere group since

1976. Michael King and Kevin Ward provided new versions of the papers.

4. Added a MODIS Atmosphere product release date table that includes the date individual Atmosphere products is available for ordering by the public from the EOS Data Gateway and the Goddard DAAC. Also included is the first data date in the available series for each product.

5. Added a PowerPoint presentation page to the REFERENCE section; thumbnails of selected slides were generated and displayed.

6. Began development of KNOWN PROBLEMS pages for each MODIS Atmosphere product.

7. Developed and implemented a template History web page for MODIS Atmosphere products (modis-atmos.gsfc.nasa.gov/MOD07_L2/history.html). These pages will help users determine when particular algorithm improvements will appear in the data. Plans are in effect to implement similar web pages for all the MODIS-Atmosphere products.

8. Updated the Showcase Images section. Thumbnails were reduced in size and a three layer (thumbnail, normal view with text explanation, and expanded view) browsing system was implemented.

9. Began the restoration of the MODIS-Atmosphere (modis-atmos.gsfc.nasa.gov) web site after a recent disk crash. In early December 2000, the modis-atmos web server crashed, and a hard drive was lost. Due to the group's lack of a system administrator, the most recent backup of the site was over 1 year old. Fortunately, Mr. Hubanks had a partial up-to-date backup of the site on his PC, and was able to quickly restore the high-level content. The remaining content (publications and product browse images) was backed up on other GSFC platforms, which Mr. Hubanks has been restoring piecemeal. Nearly all the elements of the site have been restored; a complete restoration will be completed in mid January 2001.

Eric Moody, Mark Gray, and Paul Hubanks worked on adding visualization and data processing tools to the site's Tools page. Eric Moody and Paul Hubanks worked on placing daily High Resolution (10 km) Level 3 images on the site's Images page.

MODIS product visualizations and other software tools

Eric Moody visualization work included:

- Adjustments and added functionality to the Bit Flag, Ancillary, and Level 2 visualization codes.

- Development of code to visualize Effective Radius Difference output and to compare University of Wisconsin's MOD06 IR Phase with our MOD06OD decision tree results (example shown in **Fig. 3**).

- Working with Mike Manyin (NASA GSFC) to create quick time movies in which various data sets are superimposed on a rotating 3-D globe.

Mark Gray continued to work on IDL code for viewing Level 1B RGB imagery.

Using these available tools, Eric Moody and Mark Gray visualized MODIS data for various press conferences, meetings, and proposals.

b. MODIS-related Instrument Efforts

Cloud Absorption Radiometer (CAR)

1. SAFARI 2000

Just before the SAFARI dry season deployment, the CAR was upgraded with a new data system and the addition of two UV channels. In preparation for the deployment, Charles Gatebe and Tom Arnold performed radiometric calibrations at GSFC on July 2 and a second effort that included both radiometric and spectral calibrations at the Airborne Sensor Facility, NASA Ames Research Center, from July 4-12. In addition, a radiometric calibration of the CAR was performed by Tom Arnold in Pietersburg, RSA using the Ames 20 inch hemisphere.

Charles Gatebe, Jason Li, et al. participated in CAR test flights aboard the University of Washington Convair CV-580, at Paine Field, Everett, Washington from July 12-21.

Charles Gatebe and Jason Li served as CAR instrument scientists on the UW CV-580. The CAR logged over 70 hours of research flights over seven southern Africa countries during SAFARI 2000. Post-deployment calibration of the CAR visible channels was performed on October 25 and November 1–2. Post-flight calibration for the CAR UV channels was performed on December 12 with the participation of Dr. Scott Janz, Code 916.

2. CAR Data processing

Charles Gatebe and Don Roth developed LabVIEW software for visualizing raw CAR data in pseudo-real-time mode. In addition, Gatebe wrote a LabVIEW tool for analyzing integrating sphere calibration data stored on the web site, and applying radiometric calibration to raw CAR data. Jason Li created quicklook images (e.g., **Fig. 4**) that are available from the CAR web page. One problem noted in the quicklook imagery is the presence of dark stripes associated with confusion regarding the end of an active scan. Filter wheel channels (SWIR bands) were problematic, having significant noise and reduced dynamic range.

3. CAR web site

Paul Hubanks began the redesign and re-engineering of the Cloud Absorption Radiometer (CAR) web site. Several pages have been completed. The new site is being temporarily staged at modis-atmos.gsfc.nasa.gov/car (see **Fig. 5**).

MODIS Airborne Simulator (MAS)

Several MAS upgrades were implemented by NASA Ames Research Center before the SAFARI 2000 deployment, including replacement of old dichroics, primary and secondary mirrors, redesign of port 4 dewar mounts and pressure release valve, and rewriting the L1B processing code. Post-deployment calibration at Ames indicated a substantial change in the radiometric calibration compared with the pre-deployment calibration. Use of a field integrating hemisphere to correct for radiometric changes on a flight-by-flight basis is being investigated.

Field processing and imaging of MAS data was implemented during SAFARI 2000 by Mark Gray and Tom Arnold. Processing including the creation of preliminary L1B (HDF) data sets that were available for local users within a day after an ER-2 flight. Selected L1B flight tracks were then made available on the project ftp site. Preliminary L2 products were also routinely processed in the field, including MAS versions of the MODIS cloud mask and cloud retrieval code. Optical thickness and effective radius retrievals over Namibian stratocumulus (September 11, 13, 14) were generally consistent with expectations.

Eric Moody developed an HDF output for the MAS retrieval code to make it compatible with MODIS output. The output file will include retrieval results as well as ancillary, geolocation, and QA information. Final testing of the routines is still needed.

c. MODIS-related Field Campaign and Validation Efforts

Most members of the group participated in the Southern Africa Regional Science Initiative year 2000 experiment (*SAFARI 2000*) dry season campaign (August and September 2000). The campaign capitalized on remote sensing observations from both Terra and the NASA ER-2 (with airborne versions of MOPITT, MISR, and MODIS, as well as other instruments). The remote sensing retrievals will be validated against in situ meteorological, aerosol, and cloud data from the University of Washington CV-580 aircraft and two South Africa Weather Bureau Aerocommander 690A aircraft, as well as numerous instrumented ground sites. The CV-580 also flew the CAR instrument, which was used to make BRDF measurements over various ground sites as well as stratus cloud decks. All aircraft were initially based in Pietersburg, RSA. The CV-580 relocated to coastal Namibia with 10 days remaining in the experiment for the cloud validation phase. In addition, the UK Meteorological Research Flight C-130 flew out of Windhoek, Namibia in support of SAFARI for about a week during the second week of September. Several coastal cloud flights were flown by the C-130 during that

time.

A poster summarizing a particularly useful validation day when Terra, the ER-2, and the UW CV-580 were co-located for Namibian marine stratocumulus observations (September 13) was presented at the December AGU. Example MODIS retrievals were also shown during an oral presentation as part of the AGU special session on Terra (see **Fig. 6**).

An important goal of the SAFARI 2000 experiment was to study of southern Africa fire emissions. **Figure 7** shows a MAS image of a controlled burn in the Madikwe Game Reserve, RSA. A view of such a scene from the ground is shown in **Fig. 8**.

d. MODIS-related Services

Meetings

1. Michael King attended a *Workshop on Remote Sensing of Aerosols* at Tel Aviv University, Tel Aviv, Israel on July 10-14, 2000.

2. Michael King organized and convened a session on 'Early Results from spaceborne remote sensing' at the *COSPAR* meeting, Warsaw, Poland on July 17-21, 2000.

3. Steven Platnick participated in the *IGARSS* (July 24-28, 2000) and *AGU* (December 15-19, 2000) special sessions on Terra.

4. Michael King, Steven Platnick, Charles Gatebe, Si-Chee Tsay, Jason Li, Mark Gray, and Tom Arnold participated in the SAFARI 2000 dry season campaign in Pietersburg, RSA, Swakopmund, Namibia, and Lusaka, Zambia.

5. Michael King attended the *U.S. EPA National Environmental Monitoring Technology Conference*, Boston, MA on September 19, 2000.

6. Michael King attended the *Ocean Optics XV* Conference in Monaco on October 16-20, 2000.

7. Michael King attended the *NARSTO Technical Symposium* in Querétaro, Mexico on October 23-26, 2000.

8. Michael King regularly attended weekly *MODIS Technical Team meetings.*

9. Mark Gray, Eric Moody, and Paul Hubanks attend the weekly *MODIS Atmosphere Data Processing meetings.*

10. Steven Platnick represented the atmosphere team in meetings and preparations for the NASA Headquarters Terra Briefing, December 1, 2000, and attended as well.

Presentations

1. King, M. D., S. C. Tsay, J. Y. Li, and G. T. Arnold, 2000: Airborne spectral measurements of surface-atmosphere anisotropy. Presented at the *Workshop on Remote Sensing of Aerosols*, Tel Aviv, Israel.

2. King, M. D., C. K. Gatebe, S. C. Tsay, Q. Ji, G. T. Arnold and J. Y. Li, 2000: Sensitivity of off-nadir zenith angles to the surface reflectance ratio technique. Presented at the *Workshop on Remote Sensing of Aerosols*, Tel Aviv, Israel.

3. Platnick, S., S. A. Ackerman, M. D. King, Y. J. Kaufman, B. C. Gao, W. P. Menzel, and D. Tanré, 2000: Early results from the MODIS atmosphere algorithms. Presented at the *International Geoscience and Remote Sensing Symposium*, Honolulu, HI (invited).

4. Moeller, C. C., D. D. LaPorte, W. P. Menzel, H. S. Revercomb, R. O. Knuteson and M. D. King, 2000: Comparison of early Terra MODIS emissive band radiances with collocated ER-2 based SHIS and MAS measurements. Presented at the *International Geoscience and Remote Sensing Symposium*, Honolulu, HI.

5. Dubovik, O., B. N. Holben, T. F. Eck, A. Smirnov, Y. J. Kaufman, M. D. King D. Tanré and I. Slutsker, 2000: Absorption and other optical properties of tropospheric aerosols retrieved from the measurements of ground-based AERONET radiometers. Presented at the *International Radiation Symposium*, St. Petersburg, Russia.

6. Gatebe, C. K., M. D. King, S. C. Tsay, and Q. Li, 2000: Sensitivity of MODIS 2.1 µm channel for off-nadir view angles for use in remote sensing of aerosols. Presented at the *International Radiation Symposium*, St. Petersburg, Russia.

7. King, M. D., 2000: How NASA's Earth Observing System (EOS) monitors our world environment. Presented at the *U.S. EPA National Environmental Monitoring Technology Conference*, Boston, MA (keynote).

8. Esaias, W. E., M. D. King, R. E. Murphy, V. V Salomonson, and C. O. Justice, 2000: Early results from MODIS on EOS Terra. Presented at the *Conference on Sensors, Systems, and Next Generation Satellites, EOS/SPIE Symposium on Remote Sensing*, Barcelona, Spain (invited).

9. King, M. D., S. Platnick, S. C. Tsay, S. A. Ackerman, M. A. Gray, E. G. Moody, J. Y. Li and G. T. Arnold, 2000: New multispectral cloud retrievals from MODIS. Presented at the *Ocean Optics XV Conference*, Monte Carlo, Monaco (invited).

10. King, M. D., Y. J. Kaufman, D. Tanré and T. Nakajima, 2000: Remote sensing of tropospheric aerosols from space: Past, present, and future. Presented at the *NARSTO Technical Symposium on Tropospheric Aerosols: Science and Deci-*

sions in an International Community, Querétaro, Mexico (invited).

11. Platnick, S., S. A. Ackerman, M. D. King, and W. P. Menzel, 2000: Early results from the MODIS cloud algorithms. Presented at *AGU Fall Meeting*, San Francisco, CA (invited).

12. Platnick, S., G. T. Arnold, M. A. Gray, E. G. Moody, M. D. King, S. A. Ackerman, 2000: MODIS retrievals of cloud optical thickness and particle radius during SAFARI. Poster presented at *AGU Fall Meeting*, San Francisco, CA.

III. Data/Analysis/Interpretation

a. FIRE-ACE

Tom Arnold is finishing up software for plotting reflectance libraries as a function of retrieval solution space (τ_c and r_e), for ice/liquid water and cloud particles and for a given surface albedo. These plots will be used in a paper being prepared on FIRE-ACE MAS retrievals.

b. Initial SAFARI analysis of Namibian marine stratocumulus

The final 10 days of the SAFARI 2000 dry season campaign (September 10-23) focused on Namibian marine stratocumulus clouds, as part of MODIS cloud retrieval validation activities. The MODIS Airborne Simulator onboard the ER-2 provided high spatial resolution spectral imagery. The in situ validation effort included the University of Washington Convair CV-580 and the UK C-130. In addition, a South African Weather Bureau Aerocommander 690A coordinated with Terra during continental cloud sampling. Example MODIS retrievals are shown in **Fig. 6** as discussed in section II.c.

IV. Anticipated Future Actions

1. Further analysis of cloud retrieval algorithm results and performance from MODIS Terra data.

2. Refine Level-2 and Level-3 algorithms subject to MODIS Terra results, including an above-cloud atmospheric correction algorithm.

3. Investigate use of the MODIS surface albedo product for cloud retrievals over land (instead of current ecosystem-based albedo assignments).

4. SAFARI 2000 dry season campaign (August-September 2000) data analysis.

5. Continue analysis of FIRE-ACE MAS data sets and MAS cloud retrieval code.

V. Problems/Corrective Actions

The main MODIS emphasis during the next reporting period is to implement

atmospheric corrections for above-cloud gas absorption (primarily water vapor). Comparison of cloud particle size retrievals using the three different SWIR/MWIR bands (at 1.6, 2.1, 3.7 μm) will be examined. Further refinement and tests of the ice library forward code will be made.

VI. Publications

a. Published

1. Durkee, P. A., R. E. Chartier, A. Brown, E. J. Trehubenko, S. D. Rogerson, C. Skupniewicz, K. E. Nielson, S. Platnick and M. D. King, 2000: Composite ship track characteristics. *J. Atmos. Sci.*, **57**, 2542-2553, 2000.

2. Platnick, S., P. A. Durkee, K. Nielson, J. P. Taylor, S. C. Tsay, M. D. King, R. J. Ferek, P. V. Hobbs and J. W. Rottman, 2000: The role of background cloud microphysics in the radiative formation of ship tracks. *J. Atmos. Sci.*, **57**, 2607-2624, 2000.

3. Dubovik, O., and M. D. King, 2000: A flexible inversion algorithm for retrieval of aerosol optical properties from sun and sky radiance measurements. *J. Geophys. Res.*, **105**, 20673-20696, 2000.

4. Platnick, S, 2000: Vertical photon transport in cloud remote sensing problems. *J. Geophys. Res.*, **105**, 22919-22935.

5. Platnick, S., 2001: Approximations for horizontal transport in cloud remote sensing problems. *J. Quant. Spectrosc. Radiat. Transfer*, **68**, 75-99.

6. Platnick, S., 2001: A superposition technique for deriving mean photon scattering statistics in plane-parallel cloudy atmospheres. *J. Quant. Spectrosc. Radiat. Transfer*, **68**, 57-73.

b. Accepted

7. Herring, D. D., and M. D. King, 2000: Space-based observations of the Earth. *Encyclopedia of Astronomy and Astrophysics*, Macmillan Press, in press.

8. Platnick, S., J. Y. Li, M. D. King, H. Gerber, P. V. Hobbs, 2001: A solar reflectance method for retrieving cloud optical thickness and droplet size over snow and ice surfaces. *J. Geophys. Res.*, in press.

9. Marchand, R. T., T. P. Ackerman, M. D. King, C. Moroney and J. P. Muller, 2001: Multiangle observations of arctic stratus clouds. *J. Geophys. Res.*, in press.

10. Gatebe, C. K., M. D. King, S. C. Tsay, Q. Ji, G. T. Arnold and J. Y. Li, 2001: Sensitivity of off-nadir zenith angles to correlation between visible and infrared reflectance for use in remote sensing of aerosol over land. *IEEE Trans.*

Geosci. Remote Sens., in press.

c. Submitted

11. Arnold, G. T., S. C. Tsay, M. D. King, J. Y. Li and P. F. Soulen, 2001: Airborne spectral measurements of surface anisotropy for Arctic sea ice and tundra. *Int. J. Remote Sens.*, revised.

12. Dubovik, O., B. N. Holben, T. F. Eck, A. Smirnov, Y. J. Kaufman, M. D. King, D. Tanré and I. Slutsker, 2001: Climatology of aerosol absorption in key locations. *J. Atmos. Sci.*, submitted.

VII. Awards

Charles Gatebe received the Year 2000 World Meteorological Organization's (WMO) Young Scientist Award at a ceremony presided over by the Secretary General of the WMO and held in Kampala, Uganda, which was based on his Ph.D. thesis "Characterization and Transport of aerosols at a high altitude on Mount Kenya." The award is competed for by all 185 member countries of the WMO.

VIII. Web sites

The Cloud Retrieval Group, MODIS Atmosphere, MAS, and CAR web sites can be found at:

ltpwww.gsfc.nasa.gov/crg
modis-atmos.gsfc.nasa.gov
ltpwww.gsfc.nasa.gov/MAS
ltpwww.gsfc.nasa.gov/CAR

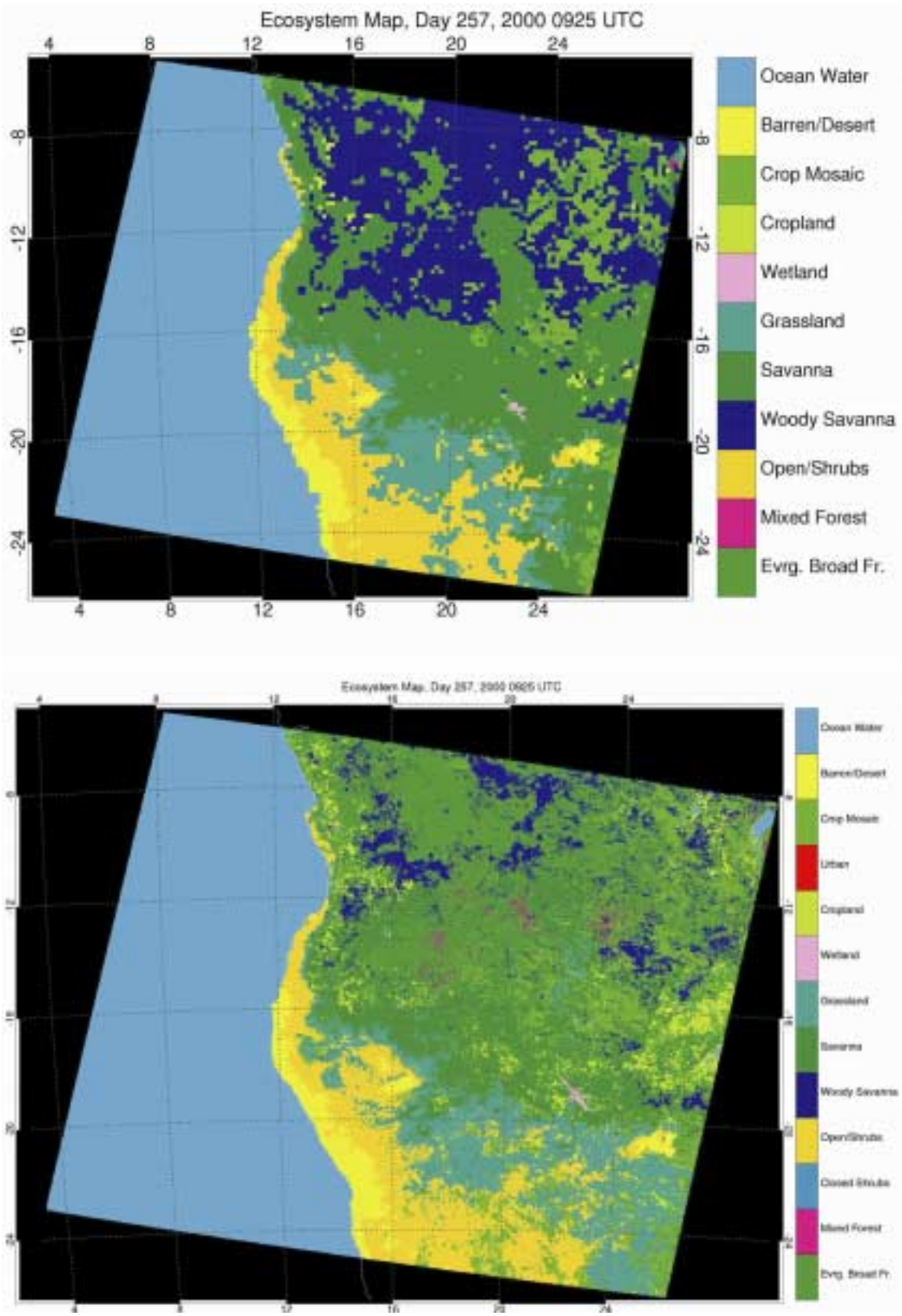

Fig. 1. New 1 km ecosystem map compared with the coarser 10 km resolution map for a MODIS granule off Southern Africa on September 13.

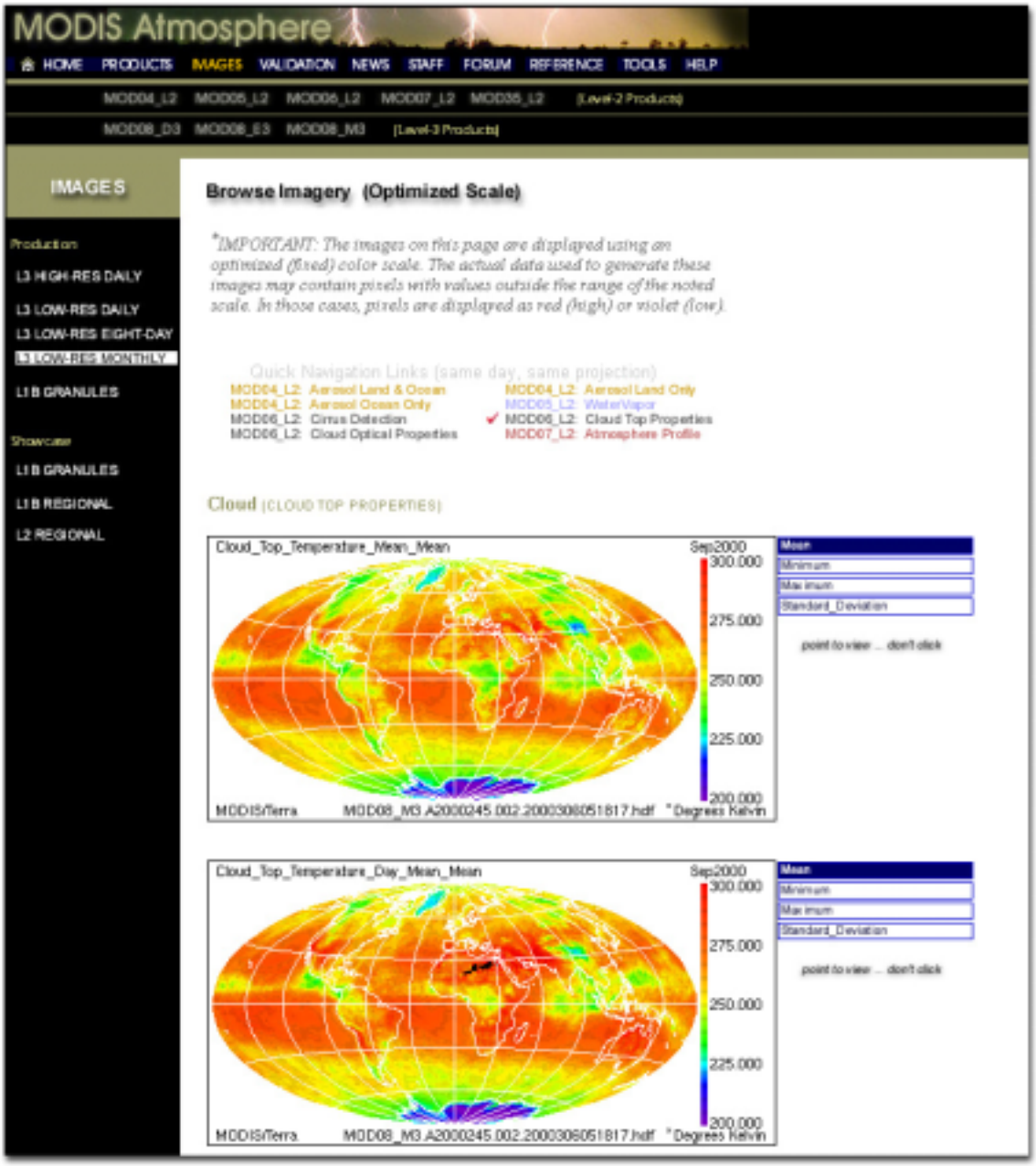

Fig. 2. Sample page from the web-based MOD08 browse system.

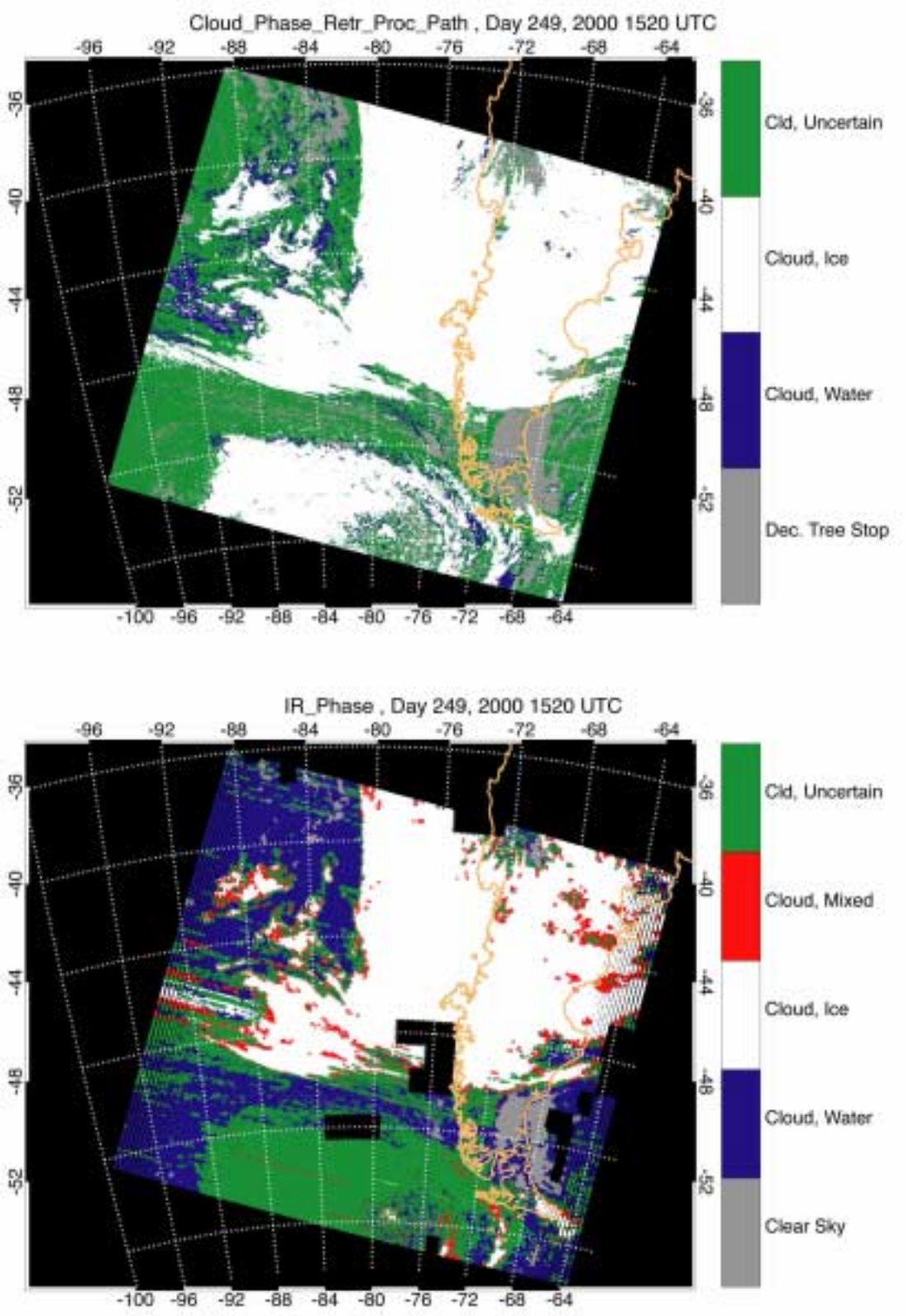

Fig. 3. Comparison of MOD06 cloud phase decision tree (derived from individual cloud mask tests) vs. the IR phase algorithm (Baum, Ackerman), for a granule over the southern tip of South America on September 5.

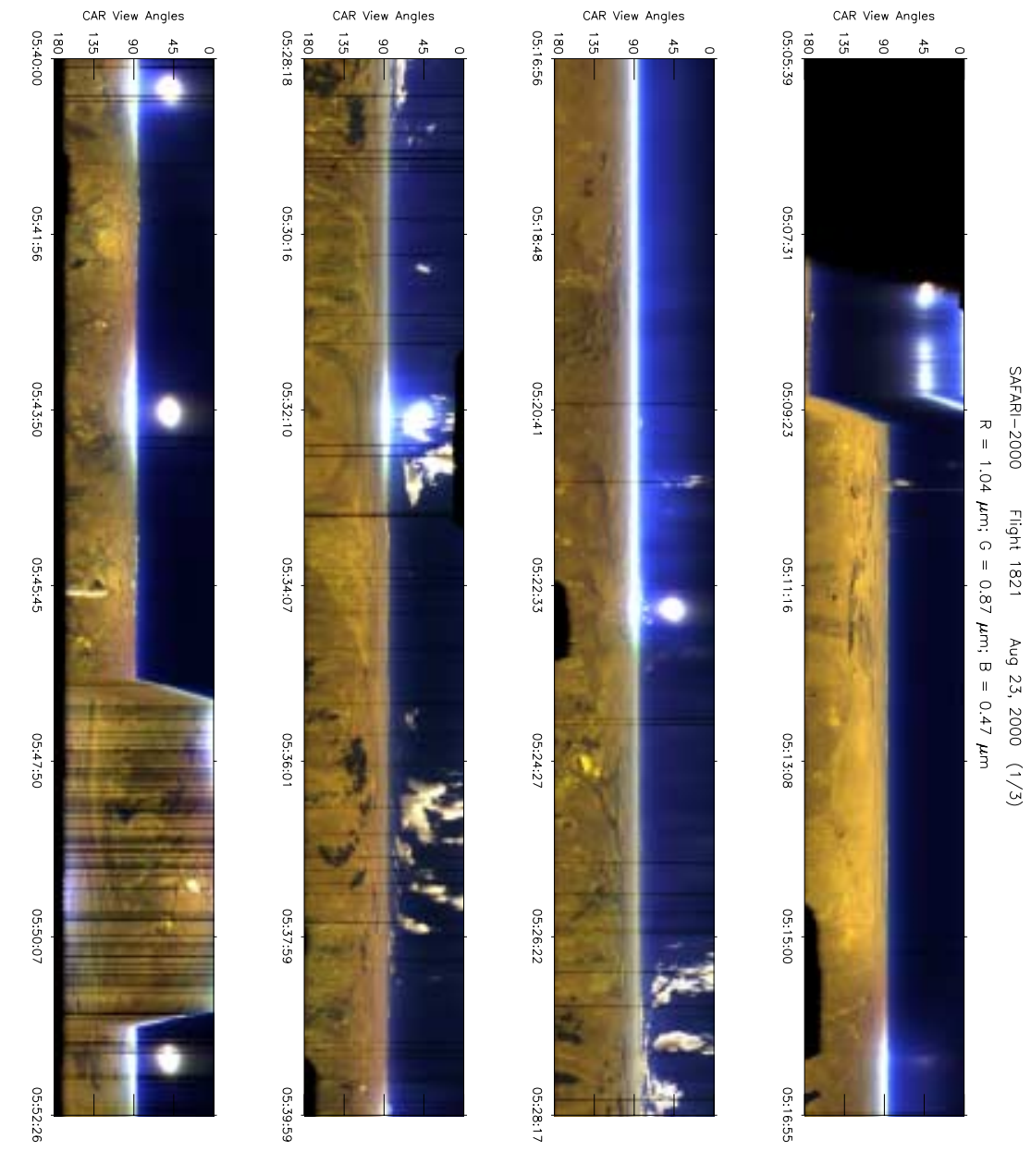

Fig. 4. Sample CAR quicklook image from August 23, obtained during the SAFARI 2000 deployment.

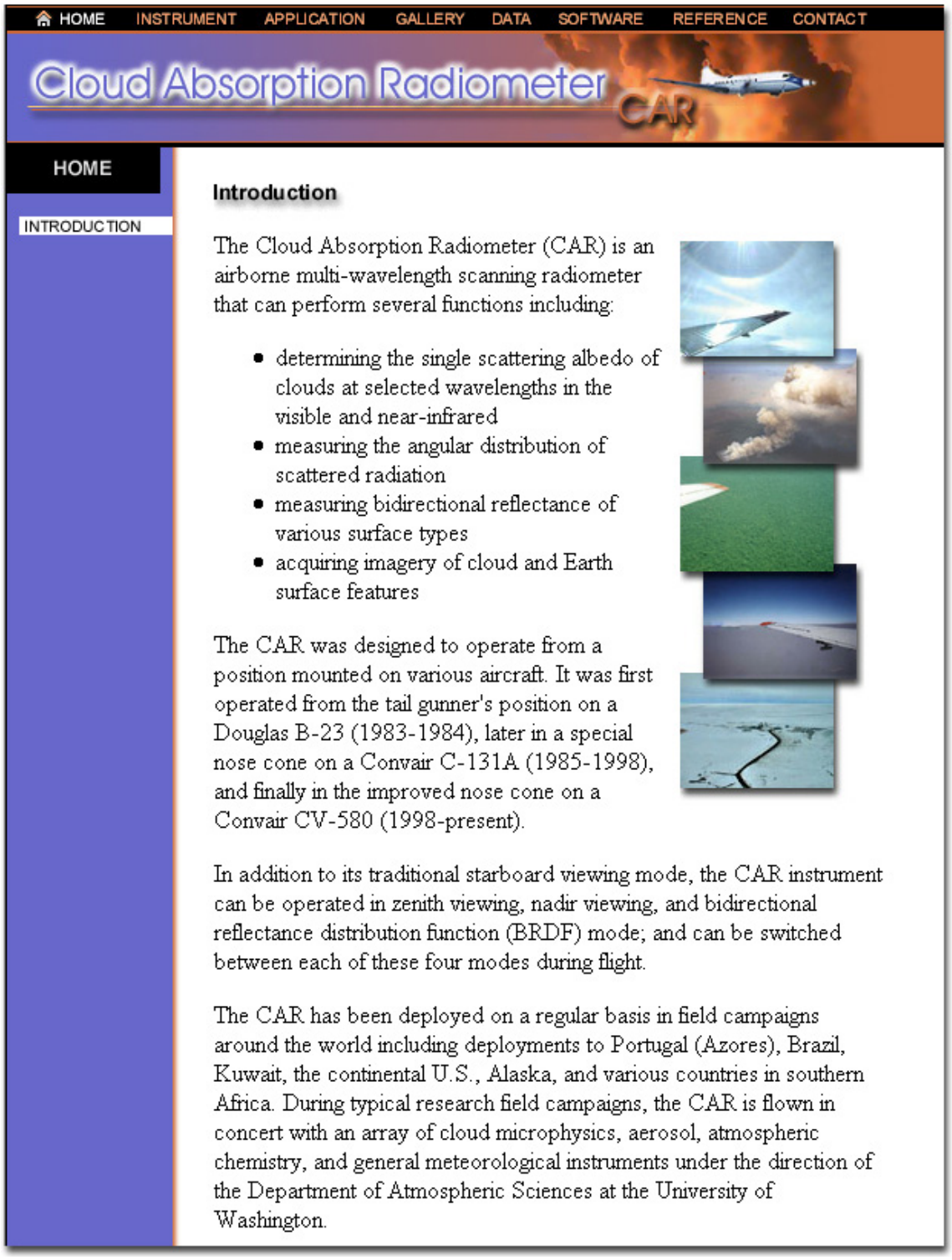

Fig. 5. New CAR web site design.

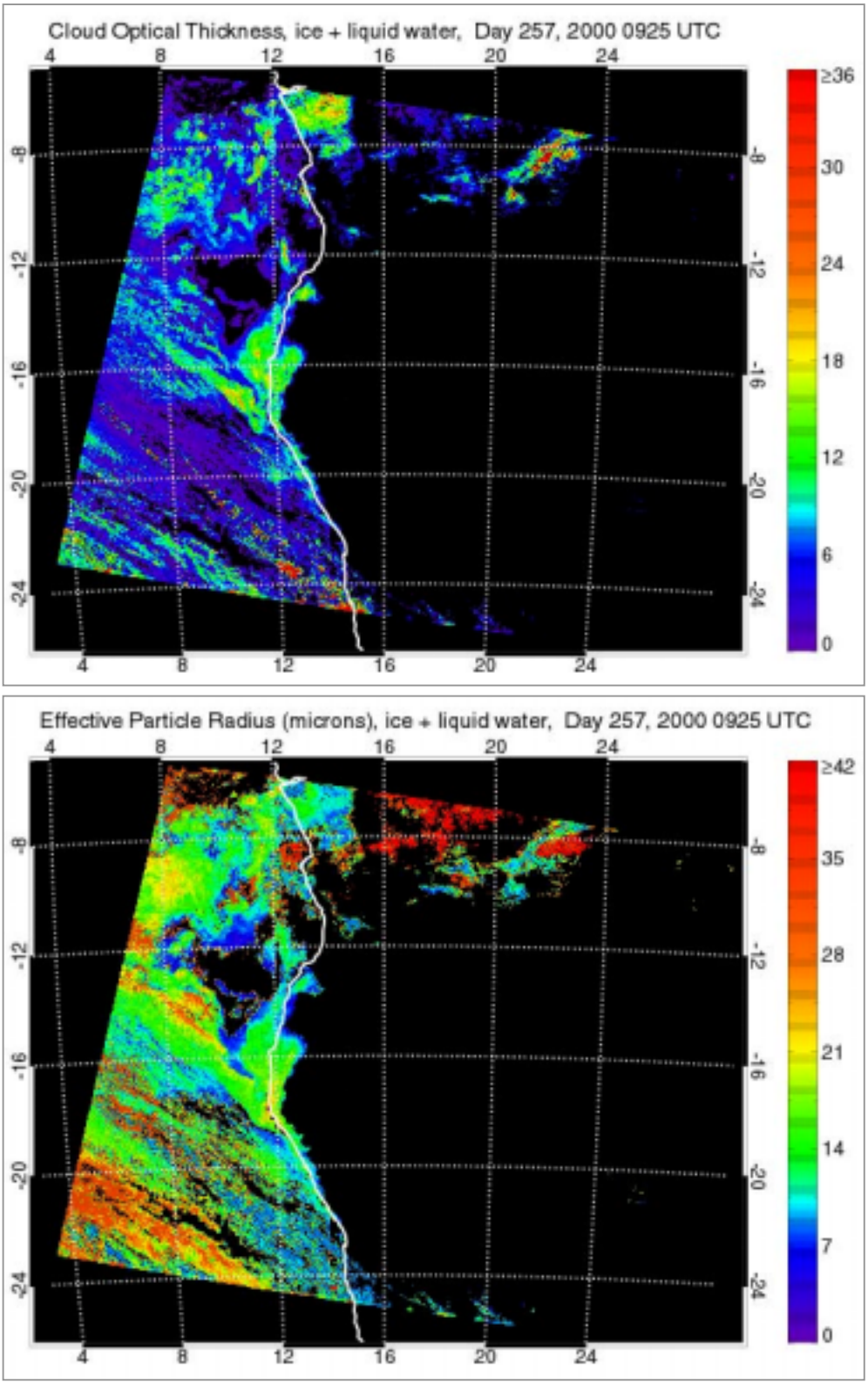

Fig. 6. Cloud optical thickness and particle effective radius retrievals from the MODIS granule on September 13. Both ice and liquid water phase cloud retrievals are shown.

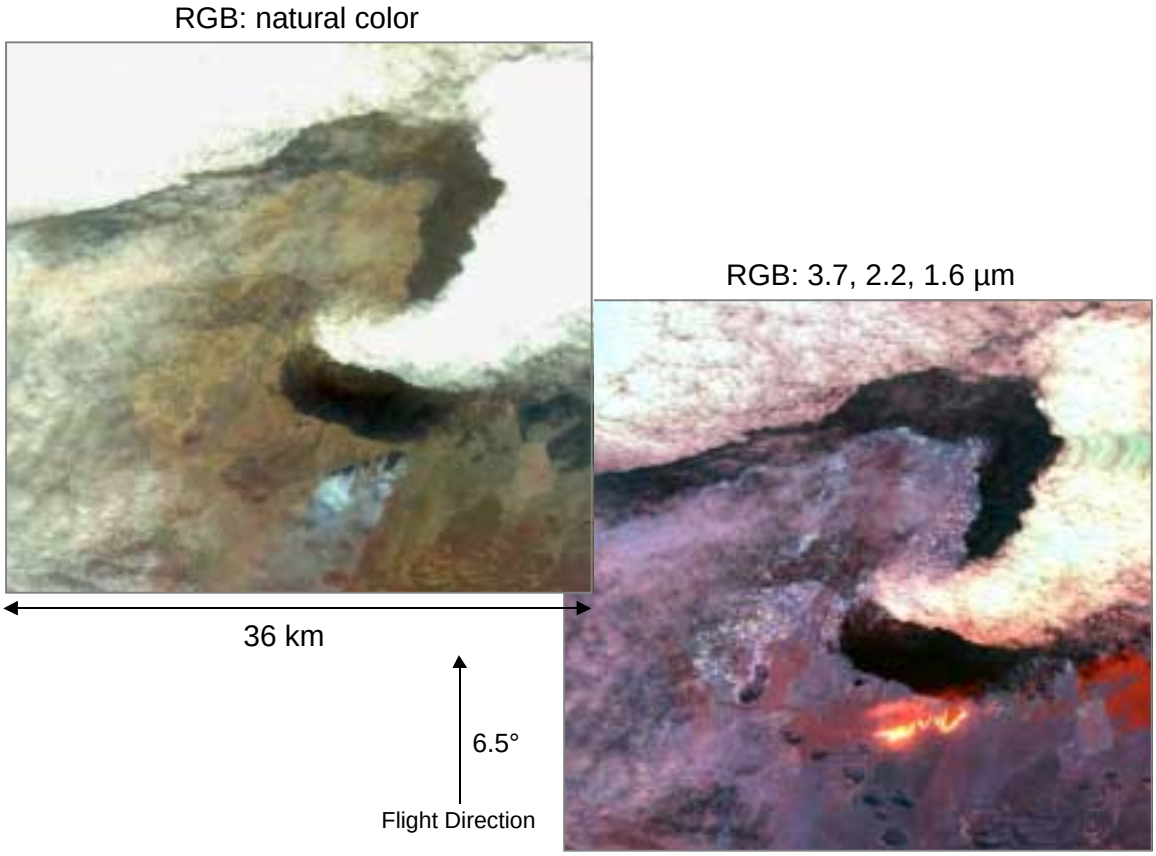

Fig. 7. MAS imagery of a prescribed burn in Madikwe Game Reserve, RSA, on August 20.

Fig. 8. Scenes from Kruger National Park, RSA.