MODIS Semi-Annual Report, December 2000

Y. Kaufman, D. Tanre, L. Remer,
A. Chu, V. Martins, S. Mattoo, R. -R. Li, C. Ichoku, R. Levy, R. Kleidman

This reports covers the **aerosol ocean** and **aerosol land** algorithm, and our involvement in the **NIR water vapor**, **cirrus** and the **fire** algorithms. It is the first to cover actual use of the MODIS data.

Main topics addressed in this period:

AEROSOL OVER LAND AND OCEAN

1 Validation of MODIS aerosol optical depth and size parameters over ocean (*Remer, Tanre, Kaufman, Ichoku, Mattoo, Levy, Chu, Martins, Li, Ahmad)*

2. Validation of MODIS aerosol optical depths over land (*Chu, Kaufman, Ichoku, Tanre, Remer*)

3. Applications to regional and urban pollution with MODIS aerosol optical depth retrieved over land *(Chu, Kaufman,Tanre, Remer)*

ALGORITHM ENHANCEMENT & DEVELOPMENT

4. Delivery of MODIS PGE04 version 2.6.0 algorithms (*Mattoo, Remer, Kaufman, Tanre)*
5. Test and implementation of 3 x 3 cloud screening using 0.47 and 1.38 μm spatial variance, adjacency effect, and percentiles in better selecting dark pixels for aerosol retrieval over land (*Chu, Kaufman, Martins)*

OTHER TOPICS

6. The PRIDE experiment and data analysis – fixing the dust nonsphericity problem (*Remer, Levy, Kleidman*)
7. Monitoring and validation of US western state fires in Montana, Idaho and Wyoming with MODIS direct-broadcasting images (*Li, Kaufman*)
8. Full implementation of the automated daily process of the generation of the MAPSS database from MODIS and AERONET aerosol and water vapor products (*Ichoku, Kaufman, Remer)*
9. Validation of MODIS level 2 NIR water vapor retrievals using ground Sun photometer measurements (*Li, Kaufman*)
10. Analysis of MODIS calibration issues in bands 5, 6, 7, 11, 20, 21, and 26 (*Li, Remer*)
11. Calibration and analysis of Microtops sunphotometer measurements (*Ichoku*, *Kaufman*)
12. Calculated spectral downward and upward flux in the visible wavelength (0.3-4.0 μm) at top of the atmosphere (*Chu, Li, Kaufman*)
13. Study of the effect of pollution on NDVI and AFRI indices from MODIS (*Chu, Li,*

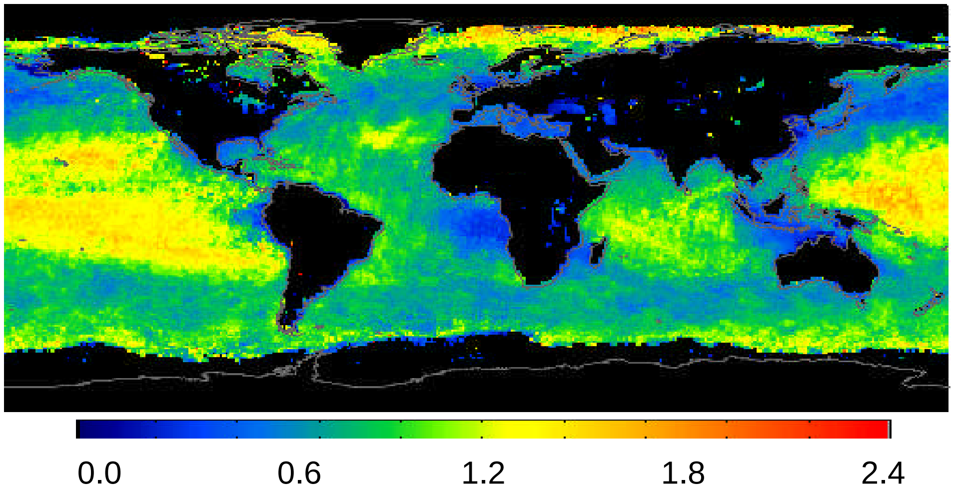
Kaufman).

14. Study of sub-pixel snow/ice detection using 0.66 and 2.1 μm channels (*Kleidman, Kaufman*)
15. Analysis of Japanese assimilation model results (*Li*, *Kaufman*)
16. Development of aerosol transport model (*Kaufman*, *Dubovik*, *Lapyonok*)
17. Paper acceptance/submission/preparation (*Kaufman, Remer, Kleidman, Ichoku, Chu, Levy*)
18. Meeting and workshop (*Kaufman, Remer, Chu, Mattoo, Li, Kleidman, levy, Ichoku*)

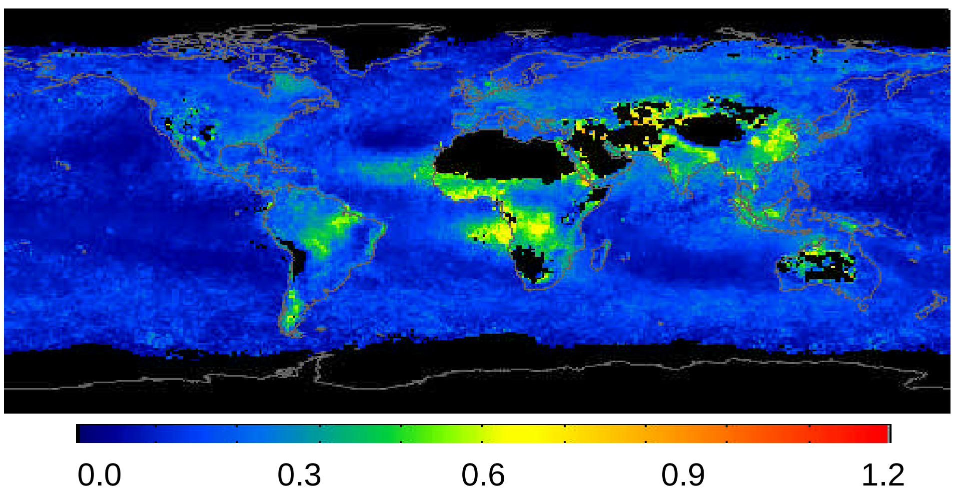
1. Validation of MODIS aerosol optical depth and size parameters over ocean

Monthly mean statistics of MODIS aerosol retrievals over land and ocean were compiled. See below for an example from September 2000 (Figure1a). Ocean MODIS retrievals of aerosol optical depth, effective radius and small mode fraction are compared with co-located observations from AERONET stations located on islands and near the coast. In a two month validation set consisting of 64 co-located points the MODIS retrievals are performing remarkably well. MODIS-retrieved aerosol optical thickness at 660 nm falls within the expected uncertainty, with the ensemble average differing by only 2% from the AERONET observations and having virtually no offset. MODIS retrievals of aerosol effective radius in the submicron range agree with AERONET retrievals to within ±0.10 μm. (Figure 1b below). The MODIS aerosol wavelength dependence matches the AERONET values reasonably well for moderate to large aerosol loading. Saharan dust, as measured during the Puerto Rico Dust Experiment (PRIDE) also shows excellent agreement in optical thickness in the visible range, but systematically deviates from ground-based measurements in aerosol size. This discrepancy in size can be explained by the nonsphericity of dust. MODIS will enable us to measure the nonspherical phase function of the dust aerosol, and adjust the algorithm. This overall excellent agreement with ground-based data provides confidence in the MODIS product and ushers in a new era of accurate spaceborne aerosol remote sensing.

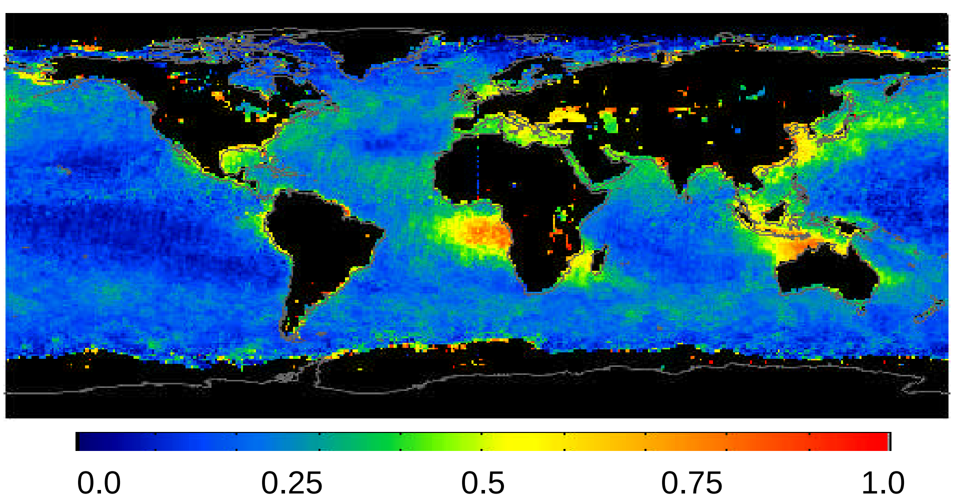
September, 2000



Aerosol Effective Radius



Aerosol Optical Depth



Small Mode Weighting

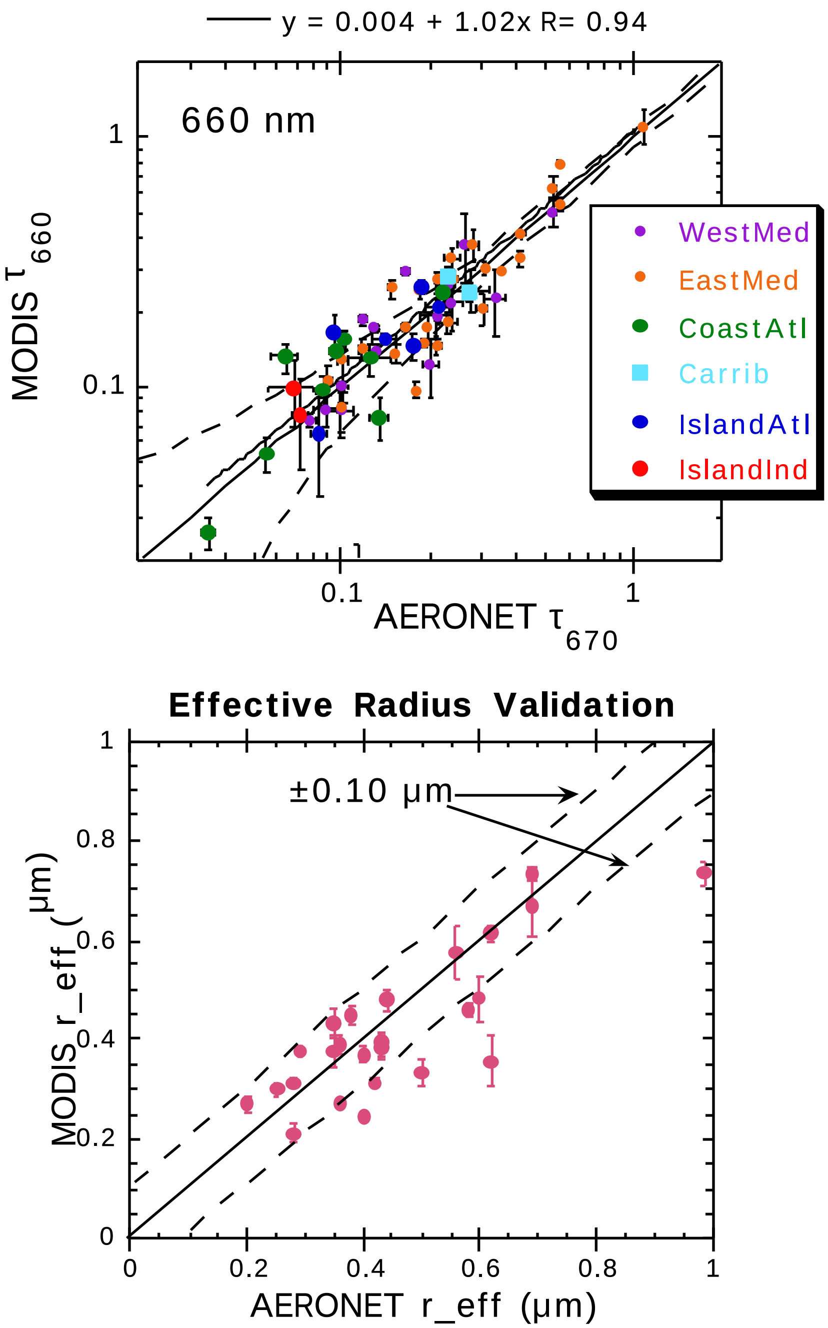
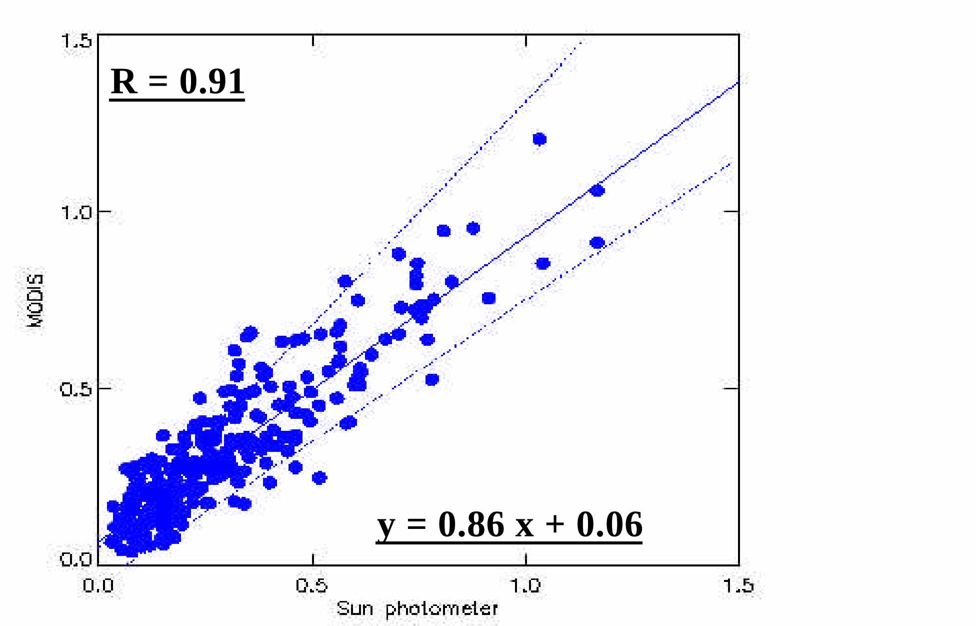


Figure 1b. Comparisons between ocean MODIS optical thickness (top) and effective radius (bottom) retrievals with AERONET observations.

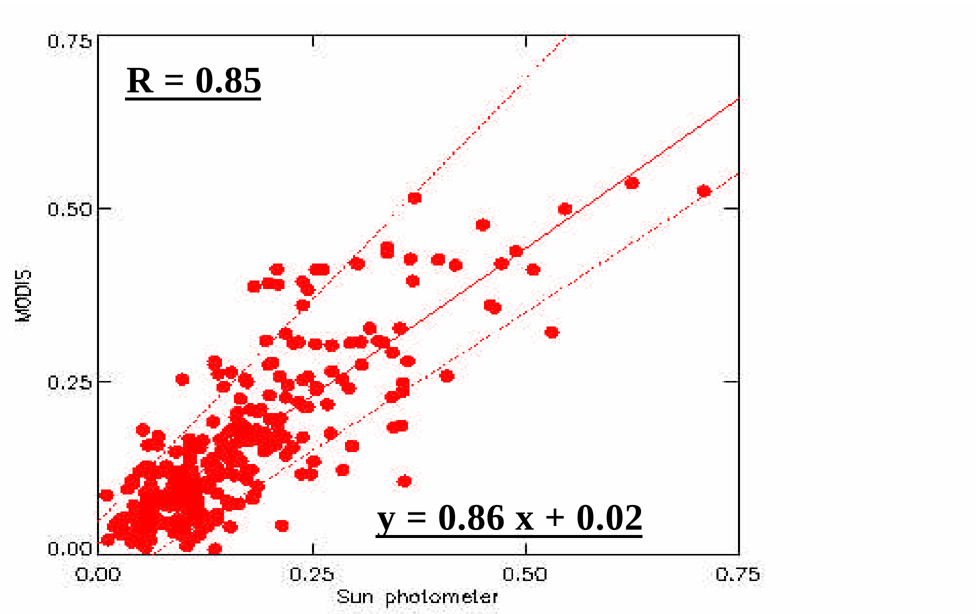
2. Validation of MODIS aerosol optical depths over land

The MODIS-retrieved aerosol optical depths and AERONET direct-sun aerosol optical depth measurements over land are compared in detail at global and regional scales. Correlation coefficients of 0.91 and 0.85 are derived globally at 0.47 and 0.66 μm wavelength with slope equal to 0.86 and intercepts 0.02-0.06 during the period of July-October 2000 (see below).

At 0.47 μm



At 0.66 μm



Using the dynamic aerosol models obtained in SCAR-A and SCAR-B field experiments and applying them to the European pollution and African biomass burning gives us confident results for the retrieval of aerosol optical depths in different parts of the world. The major problems encountered in aerosol retrievals are primarily due to the contamination of clouds (especially cloud edge and broken clouds) and snow/ice, uncertainty/variability of land surface, and aerosol models. With continuous improvements in instrument calibration and cloud/snow/ice masks, we have seen the improvements in aerosol retrieval. More detailed validations, such as view angle dependence, land-sea contrast, and wind pattern in driving aerosol transport are among the ongoing validation efforts.

3. Applications to regional and urban pollution with MODIS aerosol optical depths retrieved over land

A number of aerosol events including African and Asian dust outbreaks, biomass burning in Central America and Europe, and air pollution in Northern America and Europe are studied for possible application to regional and urban pollution. With on shore winds, MODIS aerosol retrieval with 10 x 10 km resolution is able to detect regional (600 × 400 km) and urban (100 × 50 km) pollution with strong gradient away from the source regions. The excellent agreement between MODIS-derived aerosol optical depth and AERONET Sun photometer measurements demonstrates the potential use of MODIS aerosol data in monitoring air pollution with unprecedented accuracy.

4. Delivery of MODIS PGE04 version 2.6.1 algorithms

The new PGE04 (version 2.6.0) algorithms of aerosol, water vapor and water vapor correction were delivered on October 16 and will integrated into MODIS production system some time later. This delivery w as mainly for the change of look-up tables used in aerosol retrieval over ocean (to correct low-biased aerosol optical depths in comparing with AERONET Sun photometer measurements) and in deriving total precipitable water, currently suffered due to the electronic cross talk at 1.24 μm channel. New parameter of visible reflectance in glint region is also added for the testing of possible aerosol retrieval (e.g., optical depth, single scattering albedo) over glint region. Other small changes were made in the metadata to accommodate EOS-Aqua MODIS data production.

5. Test and implementation of 3 × 3 clouds screening using 0.47 and 1.38 _m spatial variance, adjacency effect, and percentiles in better selecting dark pixels for aerosol retrieval over land

The application of spatial variance using visible reflectance is found to be more difficult over land than over ocean because of brighter and more variable surface reflectance. At shorter wavelength, the surface reflectance is smaller, which is the reason to choose 0.47 over 0.55 μm channel applied over ocean. The 1.38 μm channel is to take into account high/thin cirrus clouds. The preliminary test shows promising results. For day 110 (April 19, 2000) run, 50% less of validation points are obtained using the 3 × 3 clouds screening as compared to current MODIS clouds mask. Intensive tests are required in order to apply to all possible conditions (land surfaces in combination with various cloud types).

The adjacency effect is tested over both homogeneous and inhomogeneous surfaces. Over homogeneous surface, for instance the Amazon rain forest, small or near no change in the aerosol retrieval is found, whereas over inhomogeneous surface, for example the US East Coast region, up to 0.1 in aerosol optical depth was derived. This change may be overestimated because of the 10 × 10 km grid box, which is larger than the region normally accounted for the adjacency effect (e.g., 2 km in distance).

The selection of dark pixels using two-stage determination (based upon 10-70 percentile of reflectance at 0.66 μm and 0-70% percentile of the difference between reflectance of 0.66 and a half of 2.1 μm) is found to be better over the inhomogeneous surface, such as US East Coast. More tests are required for the combination of different cloud mask as well as adjacency effect.

6. The PRIDE experiment and data analysis

The Puerto RIcan Dust Experiment (PRIDE) observed Saharan mineral dust aerosol above the waters surrounding Puerto Rico, June 26 to July 24, 2000, with the intention of determining the physical, chemical and radiative properties of the dust, the transport processes involved, and the effectiveness of satellite retrievals of dust characteristics in this region. It involved a collaboration of researchers from the Navy (led by Dr. Jeffrey Reid of the U.S. Navy's SPAWAR center, and Dr. Ronald Ferek of the Office of Naval Research), NASA/Goddard, NASA/Ames, the University of Miami, and the University of Puerto Rico.

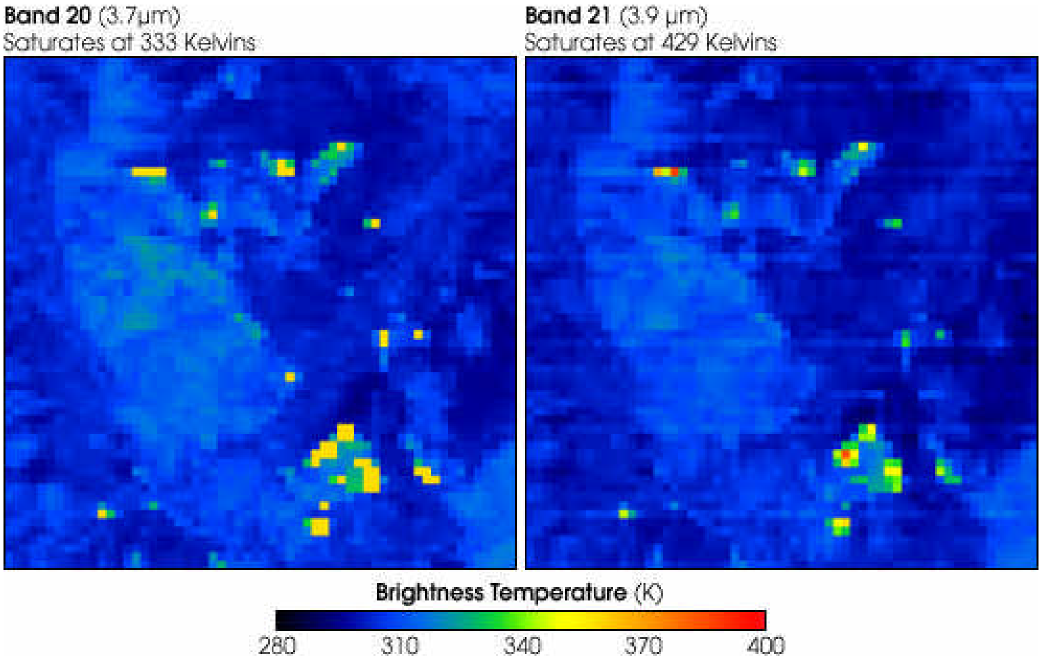
Observations were made from a twin engine Navajo aircraft carrying the Ames Airborne Tracking Sunphotometer and hyperspectral flux radiometers, an ASD spectrometer, and PCASP and FSSP particle probes. A well-equipped ground site contained a comprehensive array of in situ particle samplers, a transmissonmeter, narrow band and broad band radiometers and a lidar. Additional measurements were made offshore from University of Puerto Rico oceanographic research vessels and included both sunphotometer measurements of the aerosol and biooptical observations of the sea water and chlorophyll concentration. The experiment was supported continuously by the NRL's dust transport and prediction model. Conditions during the experiment ranged from very clean to moderate dust loading. The heavy dust events noted in Puerto Rico in early June did not re-appear during the deployment. PRIDE, the first attempt of a comprehensive Saharan dust field experiment on the west part of the Atlantic, will provide new knowledge of aerosol characteristics and help validate MODIS aerosol algorithms.

The MODIS-derived aerosol optical depths from direct comparisons with AERONET Sun photometer measurements show high correlation (~ 0.93) with slope of 1.04 at 0.66 μm but with less correlation (~ 0.88) and low-biased (slope ~ 0.8) at 0.86 μm. The MODIS-derived underestimated particle sizes indicates the nonsphericity of dust particles. The calibration test of ASD against integrating sphere and gas lamp revealed previously serious problems. The spectral line error reaches as much as 20 nm, which is far greater than the acceptable range for detecting the spectral variation of various surfaces (e.g., vegetation, snow). After the replacement of a bad detector and replacement of some electronic parts, the calibration reaches a satisfactory level. It is now undergone serious validation with ASD measurements acquired during PRIDE. The data will be used to determine the dust nonspherical properties and integrate into the MODIS algorithm

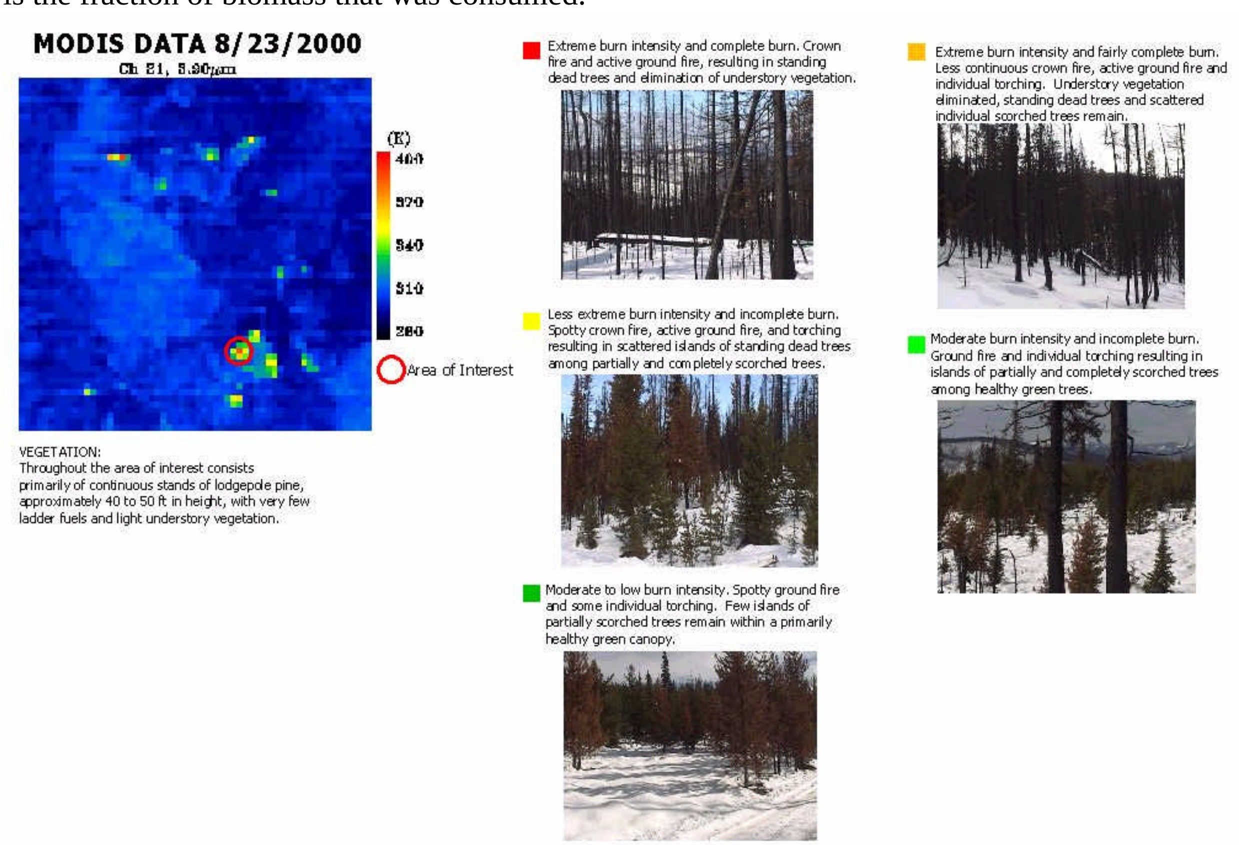
7. Monitoring and validation of US western state fires in Montana, Idaho and Wyoming with MODIS direct-broadcasting images

MODIS direct-broadcasting images are processed near real-time for detecting wild fires in western states of Montana, Idaho, and Wyoming occurring during the past August-September. It is a cooperative effort from both MODIS aerosol science team and MODIS data processing team to make such quick turnaround time for data acquisition and processing, which shows the potential usage of MODIS measurements in monitoring fire events. The US Forrest Service has begun to establish its own direct broadcasting system for acquiring MODIS measurements in order to have first-hand information about forest fires. All the data processing from level (calibrated radiance) 1 to level2 (fires and aerosol retrieval) are estimated to be within 2 hours, which is crucial for fighting forest fires.

The calculations of temperature of fire pixels are done using MODIS channel 20 centered at 3.75 μm and channel 21 at 3.95 μm. Since MODIS channel 20 was saturated at lower temperature ~ 330K, much lower than that at 3.95 μm (~ 430K), the latter is more suitable for detecting intensive fires. Shown below is the case study of fires in Montana and Idaho on August 29. The ground validation were consistent with MODIS results, which shows that the MODIS fire detection using channels 20 and 20 is able to detect forest fires with these 1-km spatial resolution channels.



The following picture shows the fire pixels that were revisited by the forest Service. The higer the pixel temperature the denser the biomass was and the hgher is the fraction of biomass that was consumed.



8. Full implementation of the automated daily process of the generation of the MAPSS database from MODIS and AERONET aerosol and water vapor products

Software of MODIS Aerosol Products Subset Statistics (MAPSS) to subset MODIS and AERONET aerosol products is completed and fully implemented into daily processing stream on Windhoek. It is used to create spreadsheet like files for validation purpose. A box of 30×30 km^2 (or 50×50 km^2) around Sun photometer site is used to calculate statistics of aerosol optical depth, Angstrom coefficient, effective radius, and other related parameters at MODIS over-passing time. Similarly, this also generates AERONET statistics within ±30 minutes of MODIS overpasses. The statistics include mean, standard deviation, maximum, minimum, and parameters from linear regression. Because of huge volume of MODIS data, the subset files are extremely useful for data analysis and archival. Aerosol size distribution and single scattering albedo retrieved from Sun photometer sky measurements are planned to be included in the near future.

9. Validation of MODIS level 2 NIR water vapor retrievals using ground-based Sun photometer

MODIS water vapor retrievals are compared with AERONET Sun photometer measurements over Africa and Kansas during August 23 and October 15, 2000 period, with correlation coefficients of 0.98 and 0.96, respectively. The MODIS water vapor retrieval values are systematically higher than the AERONET measurements. New look-up tables were generated to include additional water vapor absorption that was not taken into account previously. This new set of look-up tables should result in better comparison with ground-based Sun photometer water vapor observations.

10. Analysis of MODIS calibration issues in bands 5, 6, 7, 11, 20, 21, and 26.

Analysis of the MODIS calibration problems at bands 5, 6, 7, 11, 20, 21, and 26 was performed to solve the issue of dead detectors causing the stripping and noise in MODIS bands that affected aerosol retrievals over ocean as well as fire and cirrus clouds detection. Most of the stripping problem was fixed except for bands 21 and 26. Noise over ocean from 1.24, 1.64, and 2.13 μm bands disappeared with the new version of L1B data after switching to side B electronics.

11. Calibration and analysis of Microtops sunphotometer measurements

The measurement characteristics of five Microtops II Sun photometers have been studied to understand the instrument better and to establish its reliability for use in determining aerosol optical thickness and precipitable column water vapor. The experiment was conducted at the NASA Goddard Space Flight Center (GSFC) facility in Greenbelt, Maryland. Measurements were often taken alongside the automatic tracking AERONET master sunphotometer, which is believed to be reliable, with AOT uncertainty being less than ±0.01 at 0.440 μm wavelength and less than ±0.02 for shorter wavelengths [Holben, et al. 1998]. Therefore, in this investigation, the GSFC AERONET master sunphotometer has been used as a standard for comparison. Results show that when the Microtops are used in their original state without calibration, their average discrepancies with corresponding AERONET data vary from instrument to instrument. On the average, we found a range of differences with AERONET data of between ±0.02 and ±0.08 at 0.34 μm among the five Microtops Sun photometers. This discrepancy decreases as the wavelength increases, and the Microtops/AERONET average difference at 0.87 μm is between ±0.01 and ±0.04. However, when properly calibrated against the master AERONET instrument, the Microtops discrepancy with AERONET approaches the uncertainty levels of the AERONET AOT data very closely. In that case, the average differences between the Microtops and AERONET AOT becomes less than ±0.02 at 0.34 μm decreasing down to less than ±0.01 at 0.87 μm.

12. Calculation of spectral downward and upward flux in the visible wavelength (0.3-4.0 μm) at top of the atmosphere

The spectral downward and upward fluxes in the visible to near infrared wavelength (0.3-4.0 μm) are calculated at top of the atmosphere and at surface with assumption of sulfate, smoke and dust aerosol models. The aerosol models are selected based upon the AERONET sky measurements at most representative locations for various aerosol types. These fluxes are used for deriving weighting function for calculating aerosol radiative forcing with MODIS measurements.

13. Study of the effect of pollution on NDVI and AFRI indices from MODIS

A suite of MODIS granules over India is selected to study the effect of pollution on NDVI and AFRI. The granules separated by MODIS 16-day repeating cycle are chosen for exact Sun-satellite geometry in order to minimize the uncertainties. As expected, AFRI is much more resistant to the presence of air pollution than NDVI because longer wavelength band is used. However, due to the lack of ground-based measurements, aerosol optical depth derived from MODIS can not be validated quantitatively. We plan to use MODIS measurements acquired in SAFARI 2000 for testing NDVI and AFRI in the presence of different smoke loadings.

14. Study of sub-pixel snow/ice detection using 0.66 and 2.1 μm channels

A carefully mapped TM snow scene was analyzed to develop and test the algorithm. The relationship between 0.66 and 2.1 mm is used to identify snow pixels and distinguish them from vegetation. The algorithm is expected to be able to detect sub-pixel snow of several percents. In the process we discovered that MODIS snow algorithm is insensitive to snow contamination when trying to identify snow free pixels. 13-day continuous measurements of snow between different phases are acquired using ASD spectrometer. Sub-pixel snow contamination results in uncertainties in the estimation of surface reflectance and subsequently the retrieval of aerosol optical depth. We further applied the snow algorithm to a MODIS granule and also MODIS atmospheric correction operational algorithm to determine the fractional snow content of the pixels.

15. Analysis of Japanese assimilation model results

Japan assimilation model data sets (from Prof. Terry Nakajima) are used to study the evolution (or transport) and seasonal variation of aerosols at a global scale. Database is generated for total aerosol loading and for each individual aerosol type (dust, sulfate, salt, back carbon) as well as water vapor at twelve locations. This database is going to be compared with MODIS data for detailed analysis in terms of aerosol composition, absorption, and distribution.

16. Development of aerosol assimilation model

Aerosol assimilation model is under development via fitting satellite and ground-based aerosol remote sensing data based upon a core of aerosol transport model developed by Dr. P. Ginoux. It is expected that this fitting procedure will improve model prediction by means of correcting aerosol sources being assumed in the model. The reprogramming of the model include the following physical mechanisms

- Aerosol diffusion due to air instability in planetary boundary layer
- Cloud convection
- Dry deposition of aerosol caused by diffusion air motion in air layer near surface
- Aerosol gravitational settling

- Wet removal of aerosol
- Three dimensional aerosol advection

The redesign of the aerosol transport model are finished, including (1) regridding (degradation of the latitudinal, longitudinal, and vertical resolutions) of meteorological fields, (2) reorganization of 3D-advection processes in a form appropriate for inversion, (3) programming of the inversion code for retrieval of the source.

The development of algorithms for the retrieval of aerosol optical parameters from AERONET measurements includes (1) the subroutine changes in order to accommodate the calculation of spectral dependence of spheroidal aerosol particle optical characteristics using kernel function look up table for one wavelength and given a set of aspect-ratios, (2) the calculations of the kernel function look up table for spheroidal particles (which have been finished), and (3) the change of the retrieval code to retrieve aspect-ratio or aspect-ratio distribution of spheroidal aerosol particles.

17. Paper published/acceptance/submission/preparation

Chu, D. A., Y. J. Kaufman, C. Ichoku, L. A. Remer, D, Tanre, B. N. Holben, Validation of MODIS aerosol retrieval over land, in preparation to submit to GRL.

Gao Y., Y.J. Kaufman, D. Tanre and P.G. Falkowski, 2001: Seasonal distribution of Aeolian iron fluxes to the global ocean, Geoph. Res. Letters, 28, 29-33.

Holben, B.N., D. Tanre, A. Smirnov, T.F. Eck, I. Slutsker, Y.J. Kaufman, J. Van de Castle, A. Setzer, B. Markham, An emerging ground based aerosol climatology: Aerosol optical depth from AERONET, accepted to JGR, 2000

Karnieli, A., Y. J. Kaufman, L.A. Remer, A. Wald: Aerosol Free Vegetation Index (AFRI), accepted to J. Rem. Sens of the Environ. Sept 2000

Kaufman, Y. J., D. Tanré, O. Dubovik, A. Karnieli, and L.A. Remer, 2000: Satellite and Ground-based Radiometers Reveal Much Lower Dust Absorption of Sunlight than Used in Climate Models, accepted to GRL Jan 2001

Kaufman, Y.J., B. N. Holben, D. Tanré, I. Slutsker, T. Eck, and A. Smirnov: Will aerosol measurements from Terra and Aqua polar orbiting satellites represent the daily aerosol abundance and properties? GRL 27, 3861-3864, 2000.

Kaufman, Y.J., B. N. Holben, S. Mattoo, D. Tanré, L.A. Remer, T. Eck and J. Vaughn: Aerosol radiative impact on spectral solar flux reaching the surface, derived from AERONET principal plane measurements, accepted to JAS 2001

Kleidman, R. G., Yoram J. Kaufman, Lorraine A. Remer, Richard A. Ferrare and Bo-Cai Gao , Remote Sensing Of Total Precipitable Water Vapor In The Near-IR Over Ocean Glint, GRL, 27, 2657-2660, 2000

Kreidenweis, S.M., L. A. Remer, R. Bruintjes, R. Kleidman and O. Dubovik, Smoke aerosol from biomass burning in Mexico: Hygroscopic smoke optical model., *J. Geophys. Res.*, *in press*,2001.

Lyapustin, A.I. and Y.J. Kaufman, The role of adjacency effect in the remote sensing of aerosol over the land, accepted to JGR Sept 2000

Remer, L.A., A.E. Wald, Y.J.Kaufman, Angular and seasonal variation of surface reflectance ratios: Application to the remote sensing of aerosol over land. accepted to*IEEE Transactions on Geoscience and Remote Sensing*, Feb 2001.

Remer,L.A., Y.J. Kaufman, Z. Levin, S. Ghan, 2000: Strategy to estimate uncertainties in spaceborne measurements of aerosol direct radiative forcing, submitted to JAS

Remer, L. A., Y. J. Kaufman, D. Tanre, C. Ichoku, S. Mattoo, R. Levy, D. A. Chu, B. N. Holben, J. V. Martins, R.-R. Li, Validation of MODIS aerosol retrieval over ocean, in preparation to submit to GRL.

Sabbah I., C. Ichoku, Y. J. Kaufman, and L. A. Remer, Climatology of desert dust spectral optical thickness and precipitable water vapor over Egypt in 2000, accepted to JGR, special issue on dust.

Tanre, D., Y. J. Kaufman, B.N. Holben, B. Chatenet, A. Karnieli,F. Lavenu, L. Blarel, O. Dubovik, L.A. Remer, A. Smirnov: Climatology of dust aerosol size distribution and optical properties derived from remotely sensed data in the solar spectrum, JGR dust special issue accepted, 2000.

18. Conference/workshop

American Geophysical Union Fall Meeting, San Francisco, Dec. 15 - Dec 19, 2000. (Kaufman, Remer, Chu, Mattoo, Levy, Kleidman)

COSPAR 2000 meeting in Warszaw, Poland, on Early Terra results. Invited paper: The Earth Observing System Terra mission

IGARSS 2000 meeting in Hawaii on Early Terra results. Invited paper: Remote sensing of aerosol and aerosol radiative forcing of climate from EOS Terra MODIS instrument