MODIS Semi-Annual Report, December 2001

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

This report covers the **aerosol ocean** and **aerosol land** algorithm, and our involvement in the **NIR water vapor**, **cirrus** and the **fire** algorithms.

Main topics addressed in this period:

AEROSOL OVER LAND AND OCEAN

1. Validation and trend analysis of MODIS aerosol optical depth derived over land and ocean from 2000 to 2001 *(Levy, Kaufman, Ichoku, Remer, Chu*)
2. Validation and improvement of MODIS aerosol retrieval of dust using PRIDE data (*Remer, Levy, Kaufman*)
3. Regional variability of aerosol optical depth observed by MODIS (*Chu, Kaufman*)
4. Regional analysis of MODIS-derived aerosol optical depth and columnar water vapor *(Chu, Kaufman)*
5. Regional analysis of MODIS aerosol retrievals and DAO assimilated wind and temperature data (*Chu*, *Kaufman*, *Li*)
6. Derivation of dust single scattering albedos during African dust outbreaks (*Kaufman, Li*)
7. Theoretical basis for the surface spectral reflectance relationships used in the MODIS aerosol algorithm (*Kaufman*)

ALGORITHM ENHANCEMENT & DEVELOPMENT

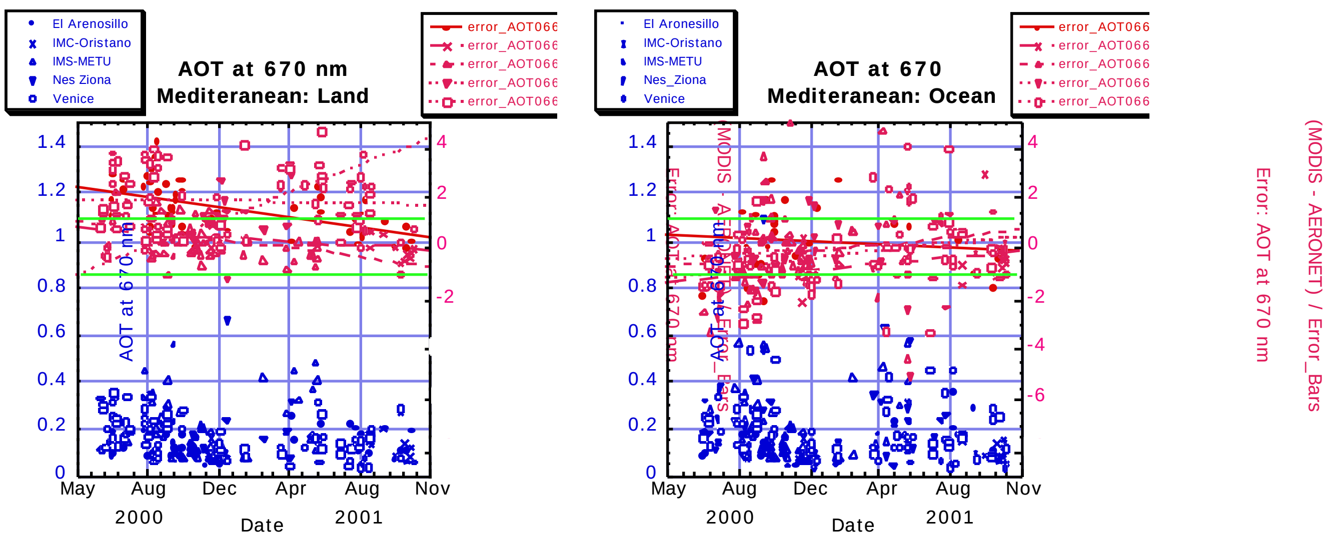
8. Percentile change from 10-40 to 20-50 in selecting dark pixels (*Chu*, *Kaufman*)
9. Extension of aerosol retrieval to 2.1 μm reflectance to 0.4 at nadir (*Chu, Kaufman*)
10. Cirrus cloud screening scheme over ocean (*Li*, *Kaufman*, *Gao*, *Tanre*, *Mattoo*)
11. Evaluation of PGE04 results on LINUX versus SGI platforms (*Mattoo*)

OTHER TOPICS

12. Enhancement/maintenance of the automated daily process of the generation of the MAPSS database from MODIS and AERONET aerosol and water vapor products (*Ichoku, Kaufman, Remer, Chu)*
13. Calibration and analysis of Microtops sunphotometer measurements (*Ichoku*, *Kaufman*)
14. Coding of transformation of MODIS fire product into climate modeling grid (*Ichoku, Kaufman*)
15. Study of sub-pixel snow/ice detection using 0.66 and 2.1 μm channels (*Kaufman, Kleidman*, *Martins*)
16. Development of aerosol transport model (*Dubovik*, *Lapyonok*, *Kaufman*,)
17. Participation in CLAMS experiments (*Remer, Martins, Kleidman, Levy, Li, Ichoku)*
18. Paper acceptance/submission/preparation (*Kaufman*, *Remer*, *Chu*, *Ichoku*, *Kleidman)*
19. Meeting and workshop (*Kaufman, Remer, Chu, Mattoo, Li, Kleidman, levy, Ichoku*)

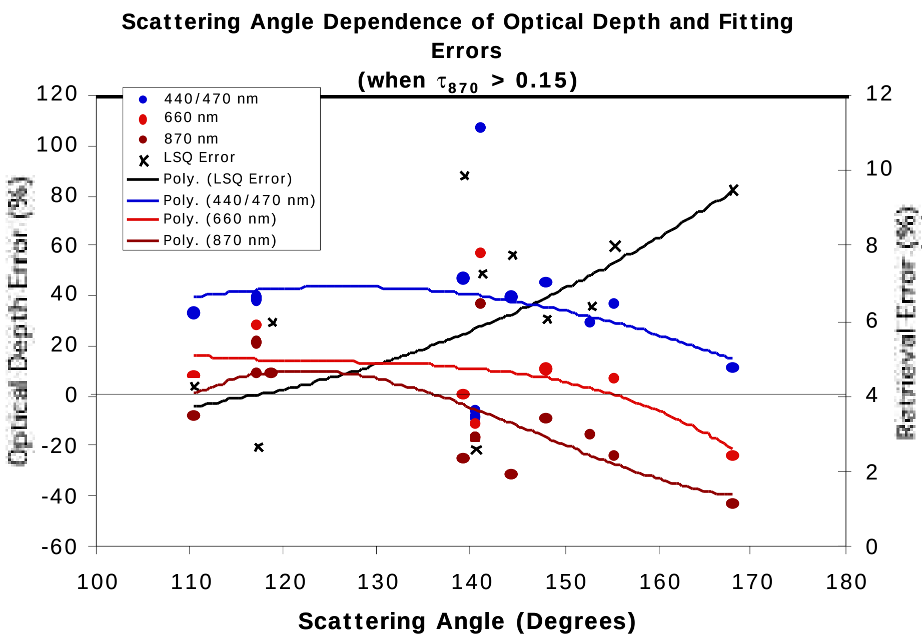
1. Validation and trend analysis of MODIS aerosol optical depth derived over land and ocean from 2000 to 2001

Since February 2000, MODIS aerosol products have been routinely generated operationally and the operational algorithm have been periodically updated, both within PGE04 code, and within upstream processing (such as Level 1B radiance). We try to answer: 1) Whether there is any obvious change in retrieval quality caused by algorithm chinage, 2) Whether the retrieval quality remain within the expected ranges. Based upon the point by point comparisons between MODIS and AERONET, there are no obvious biases due to algorithm updates. However, there are trends related to seasons and locations. Shown below are the time series of MODIS retrievals over the Mediterranean Sea region for both ocean and land at 0.66 µm as an example. Over land, for what we have known already at Venice and El Arenosillo where MODIS retrievals tend to overestimate because of water contamination (*Chu et al.*, 2002), yet the retrievals show signs of improvement toward later dates, which may be related to precipitation-promoted vegetation growth at El Arenosillo. Over ocean, there appears to be no systematic trends, yet the points are quite scattering. More detailed analyses may need to be done.



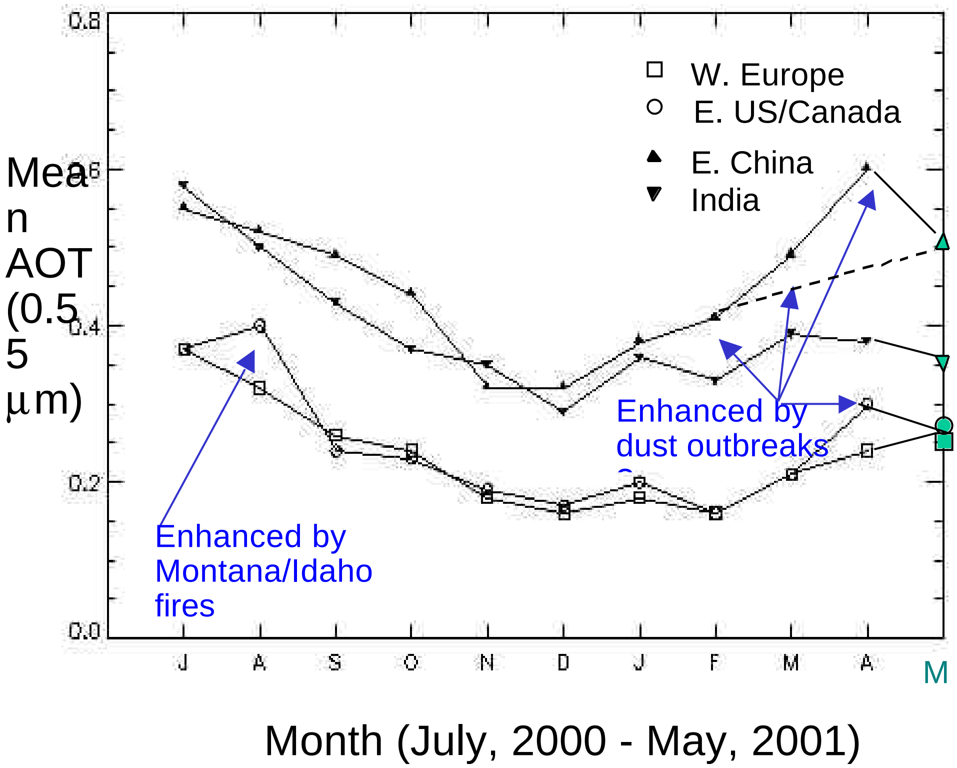
2 Validation and improvement of MODIS Aerosol Retrieval of dust using PRIDE data

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. Using data from three AERONET Sun-photometers, handheld Microtops and airborne AATS, the MODIS-derived dust optical depth at 0.66 and 0.87 µm are within previously published error bars. However, the spectral slopes of the optical depth (and angstrom exponent) do not agree those observed form Sun photometers, indicating that the MODIS-retrieved particle effective radius is too small. This discrepancy is believed to be primarily caused by the assumption of spherical particles. In fact, dust particles are most likely non-spherical. Figure 1 shows how increasing the scattering angle tends to relate to larger reflectance fitting errors. By analyzing both MODIS and sun-photometer retrievals as a function of scattering angles, we are developing a correction scheme to our inversion routine.

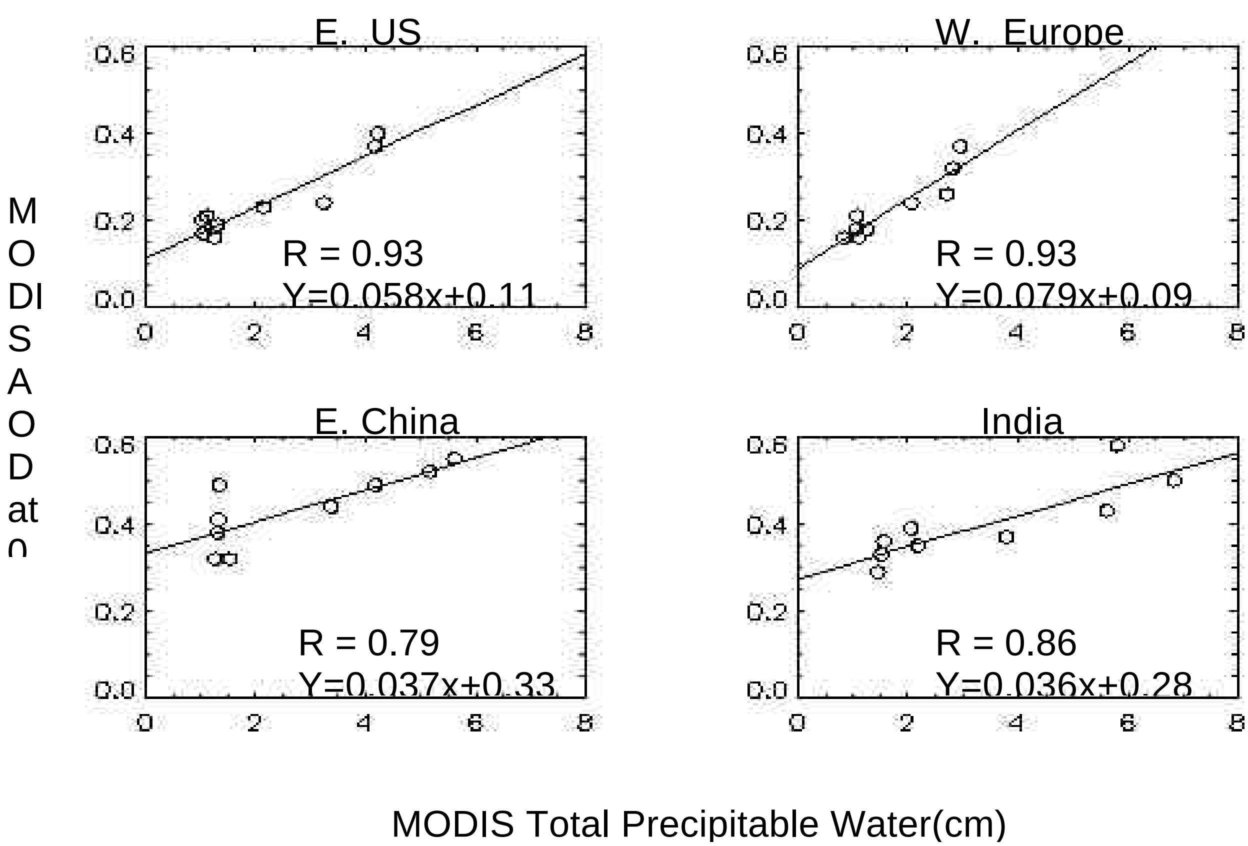


3. Regional variability of aerosol optical depth observed by MODIS

The MODIS level-3 daily global data were used to derive the regional variability of aerosol optical depth. Air pollution in Europe and North America (means ~ 0.2-0.3 at 0.55 µm) and in China and India (means about 0.4-0.5 at 0.55 µm) are compared in time series between July 2000 and May 2001. In general, two groups are identified with aerosol optical depth of E. China & India nearly double as compared to that in E. US/Canada and W. Europe, which is in agreement with the emission of sulfur dioxide of model prediction. (*Source: Global Environmental Trends, World Resources Institute, http://www.wri.org/wri/ R. Downing, R. Ramankutty, and J. Shah, RAINS-ASIA: An Assessment Model for Acid Deposition in Asia, p. 11, The World Bank, Washington, D.C., 1997*). The enhancement of dust outbreaks in China in spring season shows up to 0.15 with maximum peaked in April. The enhancement of 0.05 in E. US/Canada is not certain. The long-range transport of Asian dust is one possibility.



4. Regional/temporal analysis of MODIS-derived aerosol optical depth and columnar water vapor



For the four selected regions, aerosol optical depth and columnar water vapor are analyzed to show the difference in hygroscopicity of aerosols. The slope represents the hygroscopicity. The smaller the slope, the less hygroscopic. Two similar groups are identified, which reveal possible differences of aerosol chemical composition between these two groups of regions.

5. Regional analysis of MODIS aerosol retrievals and DAO assimilated wind and temperature data

MODIS aerosol product and DAO assimilated wind and temperature data are analyzed in regions with occurrence of air pollution sources, for example, in China and India as well as in smaller scale such as in Northern Italy and in city of Los Angles. The MODIS-derived aerosol optical depth gradients show generally good agreement with 850 mb wind speed (and direction) as well as the existence of temperature inversion layer. The nearest NASA DAO (Data Assimilation Office) GEOS-3 1°× 1° assimilated wind and temperature data to MODIS overpass time are used to avoid temporal variability. In variable terrain region, 10 m wind data gives much detailed structure of wind direction as compared to that at 850 mb (~ 1km). The change in wind direction may indicate the height of aerosol layer.

6. Derivation of dust single scattering albedos during African dust outbreak events - The difficulties in assessing dust absorption

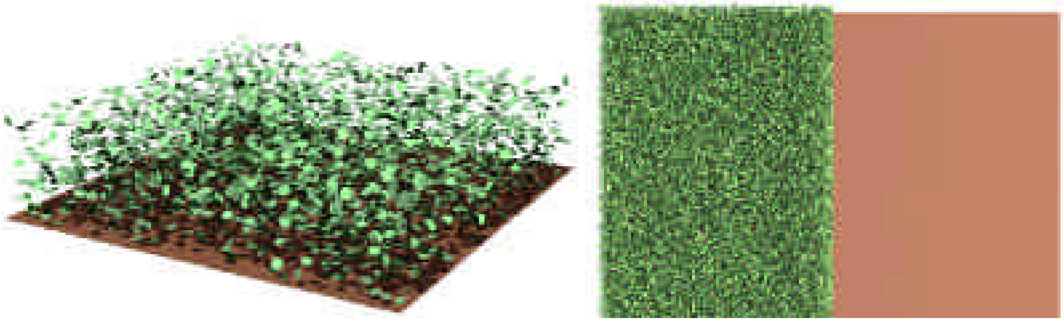
We use MODIS data for dust smoke and air pollution to derive the aerosol single scattering albedo. Results from West Africa and Arabia for dust confirm the dust small absorption measured from Landsat data and AERONET

7. Theoretical basis for the surface spectral reflectance relationships used in the MODIS aerosol algorithm

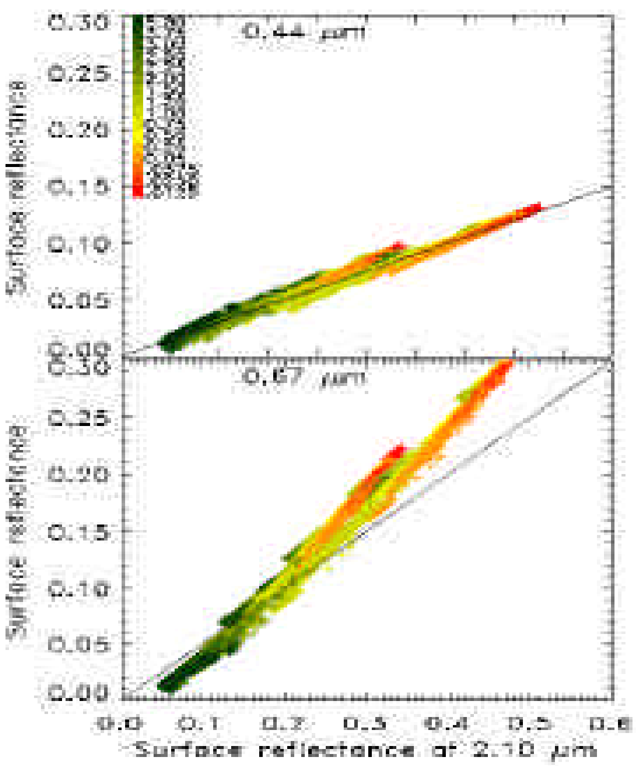
The analysis of MODIS data to derive global distribution of aerosols over the land assumes a set of relationships between the blue, ρ_{blue}, the red, ρ_{red}, and 2.1 micrometers, $\rho_{2.1}$, spectral channels. These relations have been established from a series of measurements indicating that

$$\rho_{blue} \sim 0.5\, \rho_{red} \sim 0.25\, \rho_{2.1}.$$

Successful validation also show that the relationship has a global applicability. In collaboration with scientists from the European Joint Research Center we cemented the relation better by using a model to describe the transfer of radiation through a vegetation canopy composed of randomly oriented leaves to assess the theoretical foundations for these relationships. Calculations for a wide range of leaf area indices and vegetation fractions show that ρ_{blue} is consistently about 1/4 of $\rho_{2.1}$ as used by MODIS for the whole range of analyzed cases, except for very dark soils, such as those found in burn scars. For its part, the ratio $\rho_{red}/\rho_{2.1}$ varies from less than the empirically derived value of 1/2 for dense and dark vegetation, to more than 1/2 for bright mixture of soil and vegetation. This is in agreement with measurements over uniform dense vegetation, but not with measurements over mixed dark scenes. In the later case, the discrepancy is probably mitigated by shadows due to uneven canopy and terrain on a large scale. It is concluded that the value of this ratio should ideally be made dependent on the land cover type in the operational processing of MODIS data, especially over dense forests.



Artist view of the structurally homogeneous leaf distribution implemented by the canopy radiation transfer model (left), and of the mixed surfaces used in our simulations, here for a fractional vegetation cover of 50% (right).



*Scatter plots of the simulated mixed surface reflectance at 0.44 µm (top) and 0.67 µm (bottom) as a function of the reflectance at 2.1 µm for medium and bright soils. The vegetation density is represented by the color bar, varying from dark green for f_v*LAI=5 to red for f_v*LAI=0.01. f_v is the vegetation fraction, and LAI is the leaf area index. Lines for the ratio of 1/4 and 1/2, assumed in the MODIS algorithm [Kaufman et al., 1997a] are also shown.*

8. Percentile change from 10-40 to 20-50 in selecting dark pixels

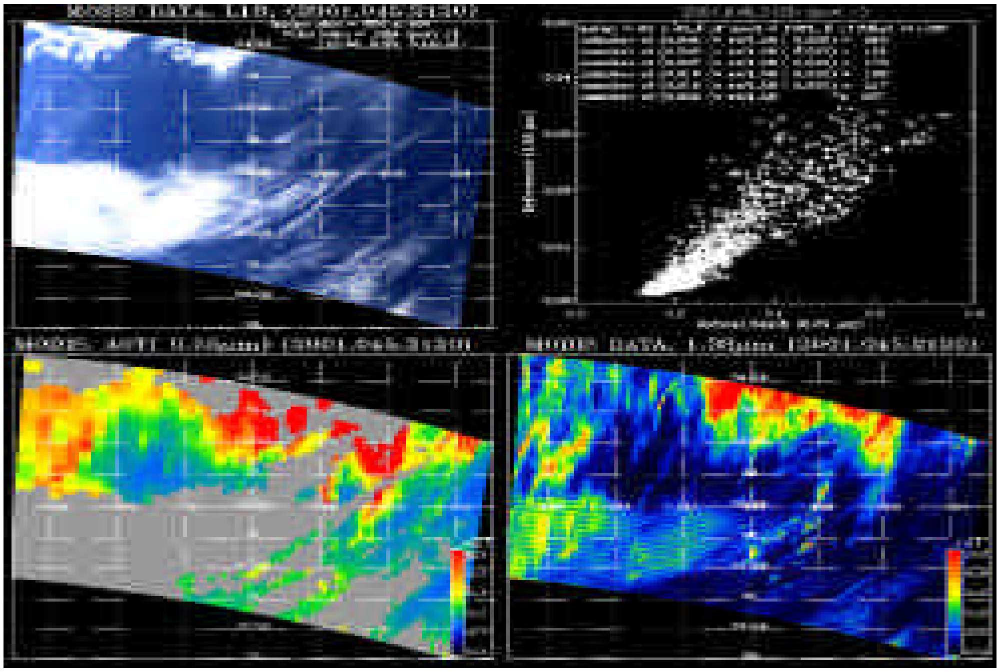
The percentile is used to derive the mean of the radiance given a 10 km ¥ 10 km grid box and then used in aerosol retrieval. The idea tested is to see the response of aerosol retrieval to the increase in percentile from 10-40 to 20-50. The test results show differences in percentage increase with decreasing aerosol optical depth, and are generally larger at cloud edge. Aerosol optical depth is 0.01 higher as a result of 20-50 percentile as opposed to 10-40 percentile under cloud free condition, and 0.02 higher in the presence of subpixel clouds. This increase in percentile from 10-40 to 20-50 is believed to move toward more symmetric sampling of dark pixels but still cautious enough for possible cloud contamination.

9. Extension of aerosol retrieval to 2.1 mm reflectance to 0.4 at nadir for 0.47 mm channel

Extension of 2.1 micron reflectance threshold to 0.4 at nadir with the inclusion of Sun-satellite sensor geometrical factor of 0.5*(1/µ + 1/sqrt(µ0)) at off-nadir (µ: cosine of satellite viewing angle; µ0: cosine of solar zenith angle) for aerosol retrievals at 0.47 mm channel. In theory, the ratio (0.25) of the reflectance of 0.47 and 2.1 mm reflectance can be extended further to higher reflectance of 2.1 mm reflectance (e.g., 0.4), while the ratio (0.5) between 0.66 and 2.1 mm reflectance begins to deviate after 0.25. Continental aerosol model is only used to derive aerosol optical depth at 0.47 mm and extrapolated to 0.55 mm.

10. Cirrus cloud screening scheme over ocean

Good separation of cirrus cloud from aerosols (dust, smoke, sulfate aerosols) by using the ratio of reflectance at 1.38 mm and 1.24 mm wavelength. Shown below is an example to illustrate the relationship between aerosol optical depth at 0.55 mm and reflectance at 1.38 mm (top right). The linear relationship depicts cirrus cloud contamination in aerosol optical depth derived over ocean.



The ratio of reflectance at 1.38 µm and 1.24 µm wavelengths show clear distinguishing between cirrus clouds and aerosols at the threshold of 0.3. With the ratio implemented in aerosol retrieval over ocean will reduce the cirrus contamination on the MODIS aerosol products.

Dust reflectance ratio at 1.38µm to 1.24 µm as a function of the dust reflection at 0.66 µm. Blue points show the cirrus contamination

11. Evaluation of PGE04 products on LUNUX and SGI Platforms

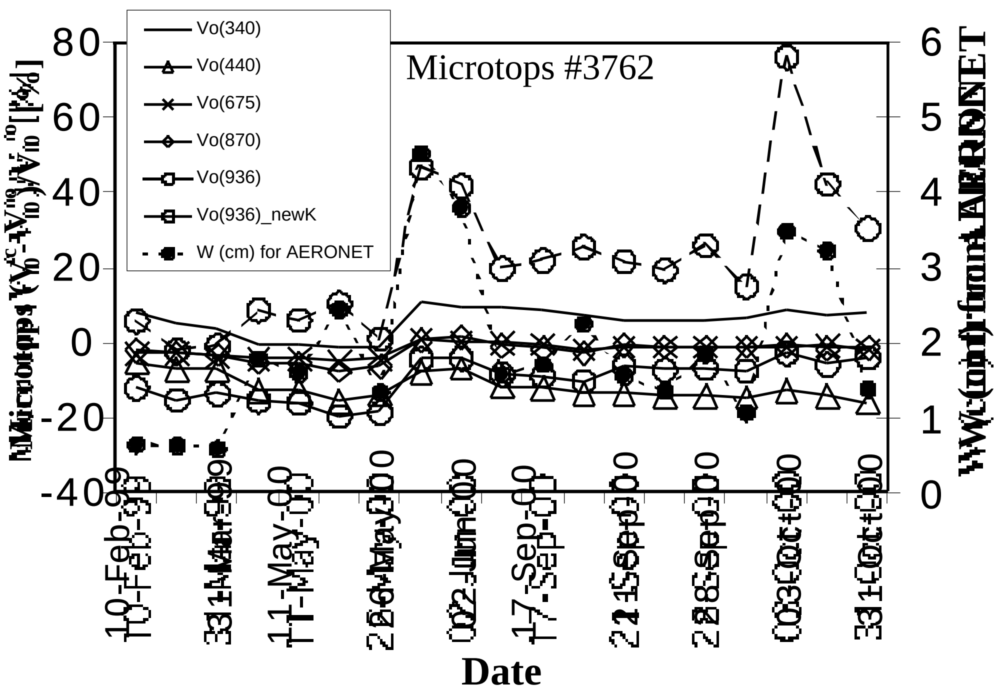
Preliminary analysis has been made to find the discrepancy of PGE04 aerosol products generated between LINUX and SGI platforms. Differences were found in small areas. However, no final conclusion is yet being drawn. Thorough investigation is in progress.

12. Enhancement/maintenance 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. In addition, the newly included MODIS aerosol products (path radiance, critical reflectance, etc.) were incorporated in MAPSS. Aerosol size distribution and single scattering albedo retrieved from Sun photometer sky measurements are planned to be included in the near future. The MAPSS software/database system, however, needed substantial maintenance during this period. First, the system sustained substantial data loss after the main computer (windhoek), on which the system resides, was shut down in June for maintenance, and the modis-atmos web server, on which the data are transmitted for easy access, was changed. Restoration was needed, and some of the scripts used for running the software and for data storage and transmission were updated. To improve the efficiency and to reduce the memory requirement, small partitioning of data processing is now being made in MAPSS.

13. Calibration and analysis of Microtops II Sun Photometer measurements

Microtops II sun photometers are handheld instruments, a few of which have been acquired by the group for the spot checking of aerosol optical depth and water vapor at sites of interest, primarily for MODIS aerosol retrieval validation. For some time, we have undertaken to do a detailed analysis of the quality and reliability of the instruments, so as to evaluate objectively their suitability for use in measuring AOT (aerosol optical thickness) and *W* (columnar water vapor) for MODIS retrieval validation. It was found that, the internal algorithm of the Microtops retrieves *W* and AOT at 936 nm incorrectly because of wrong parameterization (*k*-parameter). This is why the calibration coefficient V_0 at 936 nm shows significant dependence on water vapor (see figure). This dependence is rectified when the coefficient is recalculated with a more accurate value of the *k*-parameter (Vo(936)_newK). This is being corrected in the data acquired in many parts of the world with the Microtops sun photometers. However, it was found that when the Microtops is well calibrated and well cleaned, its AOT retrievals can be of comparable accuracy to those of CIMEL sun photometers used in the AERONET network, with uncertainties in the range of 0.01 to 0.02. A paper describing the performance characteristics of the Microtops II sun photometers was accepted to the Journal of Geophysical Research (JGR) for publication. The figure shown below depicts time series of the changes in Microtops calibration coefficients determined by transfer calibration with the AERONET master sun photometer at GSFC (V_0^c) with respect to the original factory preset values (V_0^o) for the five Microtops channels. The percent deviations, computed as [100 * (V_0^c - V_0^o) / V_0^o], are based on average V_0^c values for each calibration day. AERONET water vapor (*W*) data corresponding to the different calibration days are superimposed, to demonstrate the dependence of the 936 nm channel V_0 (i.e. Vo(936)) on water vapor. Following a re-evaluation of the instrument constant *k*, a new set of V_0 values at 936 nm were calculated (with the newly determined value of *k*=0.615 instead of the original value of 0.7487) and plotted as “Vo(936)_newK”, which show almost no dependence on water vapor.

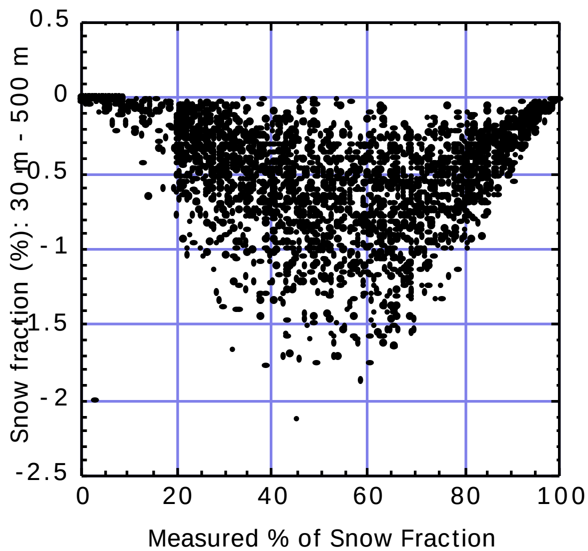


14. Coding of transformation of MODIS fire product into climate modeling grid (CMG)

The coding of generating MODIS fire product in CMG grid is initiated for the need by the climate modeling community. The radiative energy generated from fires may not be correctly characterized by climate model or it is completely absent. The use of MODIS fire channels is able to capture 80% of the radiative energy generated by the biomass burning fires. The code is currently in the initial stage for building of HDF files using the MODIS atmosphere level-3 product.

## 15.	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 μm 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 over Sierras for the same geographical area as the TM image. The concluded findings are in a paper submitted to GRL. Shown below is the snow fraction (%) difference derived from 30m (Landsat -5 TM) and 500m (MODIS) resolution data versus measured snow fraction. Small differences (<2 %) are found for various snow fractions.



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## 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 correcting the 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 modification of the aerosol transport model also includes (1) the retrieval of aerosol optical depth instead of mass concentration, (2) the retrieval of source of different dust tracers (different sizes) simultaneously. The test of retrieving dust plume (March 25-31, 1988) shows reasonable results.

The continual progresses also include (1) the improvement of computational efficiency, (2) visualization of forward simulation of aerosol transport, and (3) code testing for various aerosol events.

17. CLAMS field experiment

The Cheasapeake Lighthouse and Aircraft Measurements (CLAMS) experiment took place during July 2 -August 2 2001, around the seashore and offshore vicinity of the Wallops Flight Facility. The validation of MODIS aerosol retrieval especially over ocean is one of the goals of CLAMS. Testing the aerosol absorption over Sun glint regions has been the most important goal using the coincident MAS (MODIS Airborne Simulator) measurements with EOS/Terra MODIS overpasses. Many MODIS aerosol team members participated in the CLAMS experiment, including mission planning, execution, and data acquisition from aerosol sampler, AERONET CIMEL and Microtops Sun photometers and a sky camera to obtain snapshots of the sky conditions. The acquired data are now in detailed analysis. The first CLAMS data workshop is scheduled on February 27-28, 2002.

18. Papers published/accepted/submitted

MODIS validation

1. **Remer, L. A., D. Tanré, Y. J. Kaufman, C. Ichoku, S. Mattoo, R. Levy, D. A. Chu,** B. N. Holben, **J. V. Martins, and R.-R. Li** and Z. Ahmad, Validation of MODIS Aerosol Retrieval Over Ocean, accepted to GRL 2001
2. **Chu, D. A., Y. J. Kaufman, C. Ichoku, L. A. Remer, D. Tanre,** and B. N Holben: Validation of MODIS aerosol optical depth retrieval over land, accepted to GRL , 2001
3. **Martins, J. V., D. Tanré, L.A. Remer, Y. J. Kaufman, S. Mattoo, R. Levy**, MODIS Cloud screening for remote sensing of aerosol over oceans using spatial variability, accepted to GRL, 2001.
4. **Ichoku, C., D. A. Chu, S. Mattoo, Y. J. Kaufman, L. A. Remer, D. Tanré,** I. Slutsker and B. N. Holben A Spatio-Temporal Approach for the Validation of MODIS Aerosol Products, accepted to GRL, 2001.
5. Sabbah I**., C. Ichoku, Y. J. Kaufman, and L. A. Remer**, Climatology of desert dust spectral optical thickness and precipitable water vapor over Egypt, JGR, special issue on dust, 2001, in press.

MODIS algorithms

1. **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. *IEEE Trans. Geosci. and Rem. Sens.*, 39, 275-283, 2001.
2. **Kaufman, Y. J., D. Tanré,** O. Dubovik, A. Karnieli, and **L.A. Remer**: Absorption of sunlight by dust as inferred from satellite and ground-based remote sensing, *Geophys. Res. Lett.*, **28** , 1479-1483, 2001
3. **Tanré, 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, 2001.
4. Karnieli, A., **Y. J. Kaufman, L.A. Remer, A. Wald**: AFRI - aerosol free vegetation index, Remote Sensing of Environment, 77, 10-21, 2001.
5. 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
6. Smirnov, A., B.N.Holben, **Y.J.Kaufman**, O.Dubovik, T.F.Eck, I.Slutsker, C.Pietras, and R.N. Halthore, Optical properties of atmospheric aerosol in maritime environments. accepted to JAS 2001
7. Dubovik, O., B.N. Holben, T. F. Eck, A. Smirnov**, Y. J. Kaufman**, M. D. King, D. **Tanré** and I. Slutsker: Climatology of aerosol absorption and optical properties in key worldwide locations, accepted to JAS.2001
8. **Kaufman**, Y.J., A. Smirnov, B. N. Holben and O. Dubovik, Baseline maritime aerosol: methodology to derive the optical thickness and scattering properties, GRL in press
9. **Kaufman**, Y.J., N. Gobron, B. Pinty, J.-L. Widlowski and M. M. Verstraete, Theoretical basis for the surface spectral reflectance relationships used in the MODIS aerosol algorithm, submited to GRL.

Application and preparation for application of MODIS data

1. Gao Y**., Y.J. Kaufman, D. Tanre** and P.G. Falkowski, 2001: Seasonal distribution of Aeolian iron fluxes to the global ocean, Geoph. Res. Lett., 28, 29-33.
2. **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
3. Feingold, G., **L.A. Remer, J. Ramaprasad and Y.J. Kaufman**, Analysis of smoke impact on clouds in Brazilian biomass burning regions: An extension of Twomey's theory, accepted to JGR, 2001
4. **Kaufman, Y.J., and D. Tanré** Satellite remote Sensing: Aerosol Measurements, Encyclopedia for Atmospheric Sciences, 2001
5. **Remer, L.A., Y.J. Kaufman**, Z. Levin, S. Ghan, 2001: Strategy to estimate uncertainties in spaceborne measurements of aerosol direct radiative forcing, accepted to JAS
6. **Kaufman, Y.J., D. Tanré**, A strategy to assess aerosol direct radiative forcing of climate using satellite and ground based radiation measurements submitted to JGR, 2001
7. **Kaufman, Y.J. , R. G. Kleidman**, D. K. Hall, **V. J. Martins** Remote sensing of subpixel snow cover using 0.66 and 2.1 μm channels, revised to GRL
8. **Kaufman, Y. J. , C. Ichoku**, L. Giglio and S. Korontzi, **D. A. Chu**, W. M. Hao, **R.-R. Li**, C. O. Justice, Fires and smoke observed from the Earth Observing System MODIS

instrument –physics, data and operational use

9. **Kaufman, Y. J., D. Tanré** and O. Boucher, New satellites and ground-based aerosol measurements: implications to aerosol-climate research, Review invited by Nature, in revision.
10. **Kaufman**, Y.J., O. Dubovik, A. Smirnov and B. N. Holben, Remote sensing of non-aerosol (anomalous) absorption in cloud free atmosphere, submitted to GRL, Nov. 2001

19. Conference/workshop

IWACRI'2001 Workshop, Chongqing, China, July 22-27, 2001

IAMAS meeting 2001 Innsbruck, Remote Sensing of Aerosol and their Radiative Properties from the MODIS Instrument on EOS-Terra Satellite - First Results and Evaluation

MODIS Science Team Meeting, Greenbelt, Maryland, December 17 - 19, 2001.