1994 MODIS Annual Report

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Abstract

During 1994 we concentrated on developing and refining the MODIS algorithms. Retrieval of aerosol over land received the most attention as we addressed both the need to estimate the surface reflectance also in regions devoid of dark, dense vegetation and the choice of a dynamical aerosol model that resembles better the aerosol in nature in doing the retrievals. Preliminary data analysis revealed that we can estimate the surface reflectance in the blue and red channels as 25% and 50% of the value at 2.2 µm for surfaces as bright as $\rho_{2.2}$=0.10, or even 0.15. We made progress in developing a dynamical aerosol model, in which the size distribution varies as a function of the aerosol optical thickness for sulfate-type aerosols of industrial regions. In the future we plan to develop a similar algorithm for smoke aerosol. Over the ocean we developed under the guidance of Didier Tanre a prototype MODIS algorithm for aerosol retrieval. A prototype algorithm for fire detection and characterization was also developed. All of these algorithms were submitted as part of the beta delivery.

We expanded the MODIS work into new horizons by analyzing the cirrus effect on remote sensing using AVIRIS data and developing preliminary atmospheric corrections for the presence of thin cirrus. We play a significant role in helping Brent Holben in the continual success of the growing global sun/sky photometer network by leading the effort in data organization and software development and also by contributing to maintenance, calibration, installation and validation. We organized and carried in the SCAR-C experiment, a second in the SCAR series, which will provide data to validate the MODIS fire characteristic algorithm, will be used in testing retrieval of smoke aerosol from MODIS and testing atmospheric corrections in the presence of smoke. In collaboration with the forest service and the in situ measurements by the C131A we shall characterize the process of biomass burning and emissions and their remote sensing from MODIS.

We also contributed this year to the aerosol science by publishing a few papers on the aerosol properties, including a paper with Didier Tanré on the role of interaction between aerosol and clouds in the presence of variability of cloud supersaturation that was published in Nature. A review on remote sensing of aerosol and their forcing of climate was invited by the Dahlem conference and will appear in a book on aerosol forcing of climate.

1. MODIS Algorithms

1.1 Retrieval of Aerosol Over Land.

1.1.1 Relationship between visible and mid-IR surface reflectance.

We are using the SCAR-A data and other data sets to establish the relationship between the surface reflectance in the blue and red channels and the reflectance at 2.2µm. At 2.2µm the aerosol effect is 3-5 times smaller than in the red and blue channels and yet the 2.2 channel is not affected by emitted radiation as is the 3.75 µm channel (Kaufman and Remer, 1994). We shall use this fact and the expectation that the surface properties in the red and blue are highly correlated with the reflectance at 2.2 µm, to develop the method for remote sensing of aerosol over the land. This will expand MODIS capability beyond the use of dense dark vegetation.

Eight TM and AVIRIS images were corrected for Rayleigh and aerosol scattering and water vapor absorption using data from ground-based sunphotometers when available and from remote sensing techniques when not available. These images are from locations in Virginia, Maryland, Maine, New Jersey and California. Over two hundred targets were chosen from these images including different types of forests, other natural vegetation, cultivated fields, exposed soil, sand and residential parts of Norfolk. Corrected surface reflectances show that the 2.2 µm surface reflectances are linearly correlated with the visible surface reflectances and that the reflectance at 0.47 µm can be approximated as 25% of the reflectance at 2.2 µm while the reflectance at 0.66 µm is approximately 50% of that at 2.2 µm. A paper is in preparation on this subject.

This method extends the application of the dark target method for remote sensing of aerosol to brighter, non-forested vegetation. Furthermore, it is possible to use the 2.2 µm channel for remote sensing of dust aerosol above surfaces with reflectivity in the range of 0.10 to 0.20 at 2.2 µm because the radiative effect is small in this range.

We will continue to expand our database of surface reflectance in the visible and the mid-IR to include an even wider range of surface types. In the near future we are planning to collaborate with Luke Flynn of the University of Hawaii to measure surface reflectance of the vegetation in a dry climatic zone.

1.1.2 Aerosol Models

The retrieval of aerosol over land depends on the assumption of the aerosol optical parameters. We intend to create a model functionally dependent on aerosol optical thickness using the data collected from the Cimel sunphotometer network. Our first attempt uses the data collected during SCAR-A in the eastern United States and will represent sulfate aerosols dominant in the industrial parts of the world. In creating this model we discovered a flaw in the inversion algorithm which calculates aerosol volume distribution from sky radiances. At both the smallest and largest radii the inversion overcompensates for boundary conditions which force the distribution to be zero beyond the resolved range of particle sizes. This creates an appearance of an abundance of unphysically small and large particles. However, this is a minor flaw in that the inversion retrieves a size distribution which accurately reflects the correct optical properties of the aerosol even though the size distribution itself is in error. We use the inverted size distribution despite its errors to create the optical properties of our model because these properties are accurate. Later we will adjust the inverted size distributions to reflect more physical values by applying a process which conserves the aerosol's optical properties.

We have modeled the aerosol size distribution data as a sum of five lognormals: a coarse mode (effective particle radius, r_m, greater than 4 µm), a salt mode (r_m equal to 1.3 µm), a mode representing stratospheric aerosols (r_m equal to 0.55 µm) and two modes representing sulfates and other particles created from gases (r_m equal to 0.047µm and 0.21 µm). The two mode sulfate model represents the two different processes which create these particles. The smaller particles (0.047 effective mean radius) result from gas-to particle conversions in air. The larger sulfate particles (0.21 effective mean radius) result through cloud processes. Our model shows that at low optical thickness the 0.21 µm mode is non-existent, that as optical thickness increases both the 0.047 µm and 0.21 µm modes increase in volume density but that the rate of increase of the 0.21 µm mode is faster, and that for large optical thicknesses the 0.21 µm mode dominates the sulfate signal. Previous work using a single lognormal to represent the sulfate particles suggested a change in physical processes occurring as optical thicknesses increased above 0.20. This is the point where the 0.21 µm mode becomes significant. Our model also shows the salt mode at 1.3 µm increasing in volume density with increasing optical thickness, but that the coarse mode is not correlated with optical thickness.

Extinction , phase function and single scattering path radiance all are dominated by the two sulfate modes in our model except at the longer wavelengths. The salt mode which would have been difficult to account for on a global basis contributes less than 5 % to the total extinction for any optical thickness. We plan to compare the results of our model with existing models (Shettle and Fenn,

1979) (Vermote and Tanré, 1994) and to apply the same method for different aerosols such as smoke aerosol.

We also intend to validate the SCAR-A sunphotometer data using in situ aircraft data from the University of Washington's C-131A airplane. There are several instruments on the aircraft which measure aerosol size distribution, none of which measures ambient aerosol in the same manner as the passive sun/sky photometers. This fact will complicate the validation process. There are 13 cases of C-131A measurements spatially and temporally close to a sunphotometer size distribution retrieval. In situations with a high aerosol optical thickness, when the accumulation mode is dominated by the larger mode produced by cloud processes (r_m=0.21 µm) there is good qualitative agreement between the sunphotometers and the C-131A data. In situations with lower optical thickness when the accumulation mode is dominated by the smaller mode produced by gas conversion (r_m=0.047 µm) the agreement is less good. It is in these latter situations where the flaw in the sunphotometer inversion technique becomes apparent. In these cases we need to validate the optical properties retrieved by the sun/sky photometers with those measured by the nephelometer aboard the C-131

1.2 Retrieval of Aerosol Over Oceans.

Didier Tanré and us are working on remote sensing of aerosol loading and size distribution over the oceans. The algorithm uses the wide MODIS spectral coverage till 2.2 µm or 3.9 µm to retrieve 1-3 parameters about the size distribution, assuming the presence of log-normal modes. Preliminary algorithm was written and is being tested with simulations and sensitivity studies.

1.3 Atmospheric Correction for Thin Cirrus.

Bo-Cai Gao and Yoram Kaufman have developed a technique which uses the 1.375 µm channel to correct images for the effect of thin cirrus on retrieving the surface reflectances (Gao and Kaufman, 1995). They have previously shown that the 1.375 µm channel is especially sensitive to the detection of cirrus clouds (Gao and Kaufman, 1994). In this more recent work they not only detect the clouds, but also correct for their effect. The technique is an empirical approach which assumes a linear relationship between the path radiance at 1.375 µm and the path radiance at the wavelengths in the range of 0.4 and 1.1 µm. In this way the path radiance contributed by the cirrus cloud is subtracted from the reflectance reaching the satellite and the surface reflectance values modified only by the transmission through the cloud are retrieved.

The algorithm is being further developed and tested on AVIRIS images from SCAR-A and other experiments.

1.4 Detection of Fire Temperature and Smoke Optical Depths

Although the proposed MODIS algorithm intends to rely mostly on the special 3.9 µm channel for the determination of fire characteristics, several alternative means to detect fire temperature including the use of channels in the near-IR have been proposed. We prepared an AVIRIS image taken over Linden California showing a well developed ground fire including regions of active fire, hot surface areas, smoke of various depths, a capping cloud and surrounding undisturbed vegetation. AVIRIS measures reflectance in the range from 0.4-2.5 µm. We chose different target areas in the various regions for analysis of smoke and fire properties. Using AVIRIS's fine spatial and spectral resolution fire temperature was successfully estimated from the near-IR channels and smoke optical depths were determined.

Additional data of fires in all channels including 3.9 µm and the infrared are needed in order to progress on the fire detection algorithms. These data were acquired during the SCAR-C field experiment this year.

2. Sun/Sky Photometer Network

The Cimel sun/sky photometer network is a vital component of our MODIS algorithm development and necessary to achieve a global understanding of aerosol characteristics. We use these instruments in conjunction with aircraft- and satellite-retrieved images in order to apply the necessary atmospheric corrections. We also use the instruments to develop aerosol models and determine some of the aerosol effect on climate. The network is a collaborative effort involving several research groups, mainly under the leadership of Brent Holben and Didier Tanré. During 1994 the network grew from the original 13 instruments to a total of 32 instruments although not all of these operate simultaneously. Instruments were deployed in Brazil as part of NASA studies, in Africa as part of a French sponsored project, at world-wide LTER sites, in Canada as part of the BOREAS experiment and in the western United States as part of the SCAR-C experiment. Maintenance, calibration, installation, data retrieval and organization are major, on-going efforts. Some papers were published or in preparation from this network. A recent one is by Kaufman and Holben (1994). The network is also a prototype of aerosol and water vapor validation envisioned for MODIS and EOS.

We participate in this network by helping Brent Holben in the maintenance, calibration and installation of the instruments, as needed, and by leading the work on data retrieval (Kaufman et al., 1994) and organization. The "demonstrat" software created and implemented by Ilya Slutsker provides instantaneous retrieval and analysis of the data collected by these instruments and stored at GSFC on a workstation. The entire two-year data base is available to any approved user on an x-window terminal. Over the past year "demonstrat" has been continuously updated and improved to meet the needs of the users of the growing network. The data base now includes data collected by auxiliary instruments which are accessible with "demonstrat", a comprehensive analysis of the sky radiance data, inverted size distributions and phase functions, and a geographically based access system. We also participate in the validation of the retrieval software by performing comparisons and sensitivity studies. The water vapor retrieval algorithm and sensitivity to surface reflectance were two such validation studies completed this year.

3. SCAR-C Field Experiment

The SCAR-C (Smoke Clouds And Radiation - California) field experiment took place 19 Sept. to 8 Oct. '94. The main objectives were to collect data for development and validation of the MODIS fire detection and smoke aerosol detection algorithms, characterize the biomass burning and fire-produced smoke from remote sensing and in situ measurements, study the smoke interaction with clouds, characterize the background aerosol of the west coast, validate remote sensing algorithms and obtain images of dry zone vegetation for studies of surface reflectance in the visible and near-IR spectral regions. In these objectives we were successful in all cases except the study of smoke interaction with clouds due to the absence of clouds in each of the burning situations encountered. Y. Kaufman and L. Remer took lead positions in the organization of the experiment. Other participants in SCAR-C included D.S. McDougal, R. Cofer, B. Holben, C. Justice, and J. Conel of NASA (GSFC, Langley, JPL), P. Hobbs, D. Hegg and R. Ferek of University of Washington, L. Flynn of the University of Hawaii, D. Ward and R. Ottmar of the U.S.D.A, Elaine Prins from U. Wisconsin, Paulo Artaxo from U. Sao Paulo, Z. Levin from U. Tel-Aviv and C. Louisse from Lawrence Livermore lab.

We acquired an outstanding data set consisting of 4 prescribed burns in western Washington and one near Tillamook Oregon as well as 2 wildfires in California and several wildfire complexes in Idaho. Each research group was able to observe smoke from both wildfires and prescribed burns. There were at least three occasions where we acquired remote sensing data from the ER-2 simultaneous to in situ observations made by the Univ. of Washington aircraft. In addition, there was one situation where the smoke was observed by the JPL sunphotometers on the ground, by the Univ. of Washington plane in the smoke plume and by the ER-2 from above. The ER-2 carried the MODIS Airborne Simulator (MAS) and AVIRIS, but the lidar system was not integrated onto the plane in time for the experiment. The MAS was flown in a modified 12 channel configuration because the 50 channel version was not ready.

We took responsibility for deploying five automatic sun/sky photometers for SCAR-C. One near Ukiah OR, one in an agricultural burn area in the Willamette Valley in Oregon and two in the Sacramento Valley of California. In addition, a sun/sky photometer continued to collect data at the H.J. Andrews LTER site in Oregon. One of these instruments was moved to Owens Lake in California at the conclusion of the field campaign where it is now collecting data on dust aerosol.

We are currently collaborating with the engineers of NASA/Ames to calibrate MAS and are organizing the fire imagery from MAS and AVIRIS for analysis. We expect the analysis of the SCAR-C data to be a major thrust of our work during the early part of 1995.

4. SCAR-B filed experiment

Preparations are under way for the SCAR-B experiment in Brazil next year. We supply the scientific support for the NASA/HQR activity to organize the political scene of the experiment. In parallel scientific effort was undertaken to understand better the process of biomass burning, its effect on climate and the use of remote sensing (Kaufman et al., 1994).

5. Other issues

Two efforts that are not integral part of the MODIS activity but can be of use to MODIS. First is the understanding of the calibration degradation of AVHRR (Mekler and Kaufman, 1994) and the development of new calibration techniques based on molecular scattering over ocean, high, reflective clouds and ocean glint (Vermote and Kaufman, 1994).

Second is the understanding of the processes that govern aerosol evolution in the atmosphere and their interaction with clouds. This includes both the effect of aerosol on cloud microphysics and albedo (work under way) and the effect of clouds on the aerosol size distribution (Kaufman and Tanre, 1994). This is important to be able to assess the impact of aerosol on climate.

Publications (written or published in 1994)

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