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1. Algorithm and Software Development.

Work have been completed on all the four ATBD's. Software will be delivered starting at the beginning of next year.

- Remote sensing of aerosol from MODIS by Kaufman and Tanré. This algorithm includes both the derivation of aerosol optical thickness over the land and the oceans and derivation of the aerosol size distribution over the ocean. The method over the ocean is lead by Tanré with help of a programmer in GSFC under the MODIS support of Kaufman. The work over the land meanwhile includes only application of dark targets identified in the mid IR and applied in the red and blue channels to detect the optical thickness. We plan to study the possibility of adding the contrast technique and to develop a technique that combines MISR optical thicknesses with these from MODIS. Didier Tanré is planning a sabbatical in GSFC where he will collaborate more closely on the development of these products and work on atmospheric corrections. We started to write two codes for remote sensing of aerosol over the oceans and continents respectively. We plan to deliver first versions in the beginning of next year.

- Remote sensing of fires by Kaufman and Justice. The ATBD includes a review of the present algorithms and a first suggestion for an algorithm that can be applied to MODIS, with two channels during the day and three channels during the night. The algorithm strongly depends on the decision on the saturation level of the 11 µm channel. A detailed sensitivity study will be required for assessment of the derived products. There is also a need of a fire dynamics model to relate the measured temperatures to the fire type and rate of consumption of biomass.

- Remote sensing of water vapor by Gao and Kaufman. The algorithm, based on previously published papers, describes the use of the near IR MODIS channels centered at 0.865, 0.905, 0.936, 0.940, and 1.24 µm for remote sensing of water. Techniques employing ratios of water vapor absorbing channels at 0.905, 0.936, and 0.94 µm with atmospheric window channels at 0.865 and 1.24 µm are used. The algorithm also includes a new sensitivity study. The software will be developed by Gao and expected to be ready by the beginning of next year.

- Atmospheric corrections The Algorithm Theoretical Basis Document was completed for the atmospheric corrections for the surface reflectance and ground-leaving radiances by E. Vermote and L. Remer with C. Justice, Y.J. Kaufman and D. Tanré. The algorithm will correct for molecular scattering and gaseous absorption at launch, and for aerosol effects and bidirectional reflectance after launch when the quality of the aerosol data and BRDF products over the land will be verified. The algorithm also addresses corrections for adjacency effects and cirrus contamination.

2. Field Experiments and Validation Networks

SCAR -A

The first of a series of the SCAR experiments SCAR-A (Sulphates Clouds And Radiation -- Atlantic) took place July 12 to July 28 at Wallops Flight Facility. It was designed primarily to study clouds and aerosols simultaneously from satellite instruments (NOAA AVHRR and Landsat TM), airborne instruments (MAS, AVIRIS and in situ instrumentation) and a ground-based sunphotometer network. Other objectives included obtaining a database from which to validate MODIS algorithms, to measure surface reflectance properties and to study cirrus clouds. The experiment consisted of the ER-2 aircraft carrying the MODIS Airborne Simulator (MAS), the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and a RC-10 mapping camera, and the University of Washington's C-131A research aircraft carrying a wide variety of instrumentation. In addition a ground-based sunphotometer network was installed and supplemented by moving ground stations and light aircraft carrying sunphotometers. Abnormal meteorological conditions which caused the flood of '93 in the midwest also affected the weather in the mid-Atlantic region, the region of our interest. During the experiment an unusual amount of cloud-free and sometimes non-humid conditions occurred. The C-131A flew seven flights characterizing the aerosol and clouds onshore and off-shore, at various altitudes and under different meteorological patterns. This aircraft also measured surface bidirectional reflectance over ocean, deciduous and coniferous forests. The ER-2 also flew seven missions and obtained excellent data to validate MODIS algorithms for atmospheric correction, aerosol retrieval and cloud property retrieval, including cirrus clouds. The measurements during SCAR-A included haze free and hazy days. during which satellite data (Landsat TM and AVHRR) were acquired simultaneously with the ground based and airborne measurements. Two missions intercepted Landsat overpasses and three missions intercepted AVHRR overpasses. The experiment was a collaboration between our group and that of Mike King and Paul Menzel as well as Peter Hobbs group led by Dean Hegg.

Planning for SCAR-C

The SCAR-C (Smoke Clouds And Radiation -- California) field experiment is planned for September or June '94. The main purposes of this experiment are to collect data which will help validate MODIS fire detection and aerosol detection algorithms. Contact was made with Wei-Min Hao of the University of Montana about the possibilities of the National Forest Service providing us with a control burn. Control burns must take place before actual fire season beg It is too dangerous. June also corresponds to the time that Michael King's group would be flying the MAS from AMES. He has agreed to allow us to fly the ER-2 with the MAS once during his reserved time as long as his group's needs remain the highest priority. The advantages of June include the predictability of a pre-set fire plus the MAS calibration would be the responsibility of King's research group. The disadvantages will be the coordination of the weather and the fire-setting team under the restrictions of "second priority" on the aircraft. Discussion continues. Several other MODIS team members plan to participate, including Drs./Profs. Strahler, Wan, Huete, Justice and Menzel. We are in contact with Robert Green at JPL regarding creative ways of utilizing AVIRIS data both past and present without paying the high costs.

<u>Sunphotometer Network</u>

The moveable network of the CIMEL sun/sky radiometers developed by Holben and Tanré and purchased by MODIS support for Kaufman, demonstrated its strong ability in the Eastern US during SCAR-A and the rest of the summer. Real time analysis of the aerosol loading and size distribution were available all the time from up to 5 locations. We plan to deploy some of the instruments in Bermuda and Barbados and later in China to generate a data set that will help us to understand the optical properties of aerosol, and to improve the aerosol models used in remote sensing.

3. The MODIS 1.38 µm Channel.

The new 1.38 µm channel has been implemented on MODIS. An extended abstract on the application of this channel for remote sensing of high clouds and stratospheric aerosols from space was written by B.-C. Gao and Y. J. Kaufman, and submitted to the SPIE93 conference in Florida. B.-C. Gao presented the paper. The discovery of this channel was based on the analysis of high spatial and spectral resolution imaging data measured by the NASA/JPL Airborne Visible Infrared Imaging Spectrometer (AVIRIS). Under normal atmospheric conditions and in the absence of high clouds, this channel is black due to the total absorption by atmospheric water vapor. When high clouds are present, this channel detects solar radiation scattered by these clouds. This channel may also be useful for remote sensing of stratospheric aerosols when aerosol concentrations are moderate to large and when the atmosphere is otherwise clear.

4. Derivation of Aerosol Models for Atmospheric Correction

The SCAR-A sunphotometer almucantar data were inverted to produce a data set of aerosol size distributions. Preliminary comparison of these inverted size distributions with the size distributions simultaneously measured aloft from the C-131A aircraft of U. Washington show excellent agreement.

The size distributions calculated from sunphotometer data were averaged and sorted according to aerosol optical thickness. Log normals were fit to represent the accumulation mode at each of the aerosol optical thicknesses. The data show that at low aerosol optical thickness, the particles size in the accumulation mode remains constant. Larger optical thicknesses represent a more aged aerosol which both grows in size (increases radius) and becomes more uniform in size (smaller standard deviation). The following model best describes the characteristics of the accumulation mode as a function of aerosol optical thickness for our data.

when $\tau_{670} < 0.20$ then $\sigma = .485$ $r_g = 0.0011$ μm

when $\tau_{670} > 0.20$ then $\sigma = .0.153\tau^{0.616}$ $r_g = 0.163 + 0.248 \log(\tau)$

if $r_g < 0.0011$ then $r_g = 0.0011$

if $\sigma > 0.485$ then $\sigma = 0.485$

where τ_{670} is the aerosol optical thickness at 670 nm, σ is the mode standard deviation and r_g the mode radius in the log-normal distribution. Further work will attempt to model the other modes in the size distributions. These models will be used to do atmospheric corrections on the SCAR-A data base, and will later form the basis for a model for remote sensing of aerosol from MODIS and corrections for its effect over the land.

5. Surface Characterization for Remote Sensing of Aerosol

The effort for surface characterization continues, and was used as a basis for the ATBD on aerosols. In this effort we are analysing th relationship between the surface reflectance at 2.13 μm and that at 0.47 and 0.66 μm. Currently Landsat TM data are being analyzed for the surface properties in the solar spectral region. From TM images over Northern Virginia and Maryland area, it is found that for a 1 km MODIS pixel, a 0.2 pixel misregistration along one direction results in an error of 2-3% in surface reflectances from TM band 4 (~0.86 μm), 3-5% from TM band 5 (~1.64 μm), and 7-10% from TM band 7 (~2.2 μm). Images from TM band 7 (~2.2 μm) have largest spatial variability.

TM images from the SCAR-A region, corresponding to SCAR-A missions #1 and #8 are also being analyzed for surface properties. A database is being collected which will provide the TM channel reflectances for 50 selected surface targets covering the region from the Great Dismal Swamp to the Pine Barrens in the north.

Targets include sandy beaches, urban zones, cropland, estuaries, inland water, bay water, coastal ocean, deciduous forest and pine forest. These same targets will be identified in AVIRIS and MAS images and the reflectances measured by these two instruments calculated. We will then have an intercalibration of TM, AVIRIS and MAS. Using the sunphotometer data collected during the remote sensing overpasses we will be able to atmospherically correct the apparent reflectances measured by the sensors and characterize the surface reflectance for these different targets.

Reflectance spectra of different surface targets compiled by Bowker et al. (1985) have been processed so that the data set can be viewed efficiently using the Interactive Data Language (IDL). It is found that the Bowker's data set has limited values for remote sensing simulation studies.

6. Spectral Properties of Smoke and Clouds

The AVIRIS data of a fire smoke and clouds formed downwind from the fire were analyzed and are being compared with radiative transfer computations. Very different properties of the smoke were detected for smoke processed by the cloud that was formed on top of the fire from the properties of smoke not processed by the cloud. From the AVIRIS data, we found that smoke is readily observable in images between 0.4 and 0.75 µm. The smoke effect decreases with increasing wavelength. It is difficult to observe smoke from images beyond about 1 µm. A paper on this research was submitted to the AMS conference.

7. Theoretical Studies

A theoretical paper was written on the effect of variability of cloud supersaturation on sulfate aerosol size distribution and concentration and on the resulting CCN concentrations. The paper by Kaufman and Tanré is now being revised to the journal Nature. Using a computer model we show that in the presence of variability of the cloud supersaturation the amount of effective CCNs is increased up to 4 times from that in the absence of such variability. Therefore previous assesments published in Nature and Science that the aerosol indirect effect was overestimated and can be ignored were premature.

8. Interaction of Aerosols with Clouds

Dust Particles and clouds.

Collaboration with Visiting Scientist Zev Levin led us to examine several AVHRR images for evidence that Saharan dust plays a role in cloud formation over the Mediterranean. Preliminary results are encouraging. At least one image clearly suggests that the dust is being scavenged by a cloud.

Smoke Particles and Clouds

The AVHRR data of smoke and clouds over Brazil was re-analyzed in order to look for the effect of smoke on thin clouds. The work is being done by Y. J. Kaufman, R.S. Fraser and M. Lawrence (a summer student in 1992). The results were presented in the first IGAC conference in Eilat in April. While for the thicker and higher clouds a larger effect was found on their microphysics, since the initial aerosol concentration in that altitudes is lower, the albedo did not change since they were already bright and the extra brightness due to extra CCN is compensated by absorption by graphitic carbon. For the lower thinner clouds, the change in the microphysics was smaller, but the clouds did become brighter. These effects were more pronounced in the central part of the Amazon basin where deforestation fires take place and there is a larger variability in the smoke concentration. The effect was much smaller in the southern part where Cerrado fires are dominant, due to the diffusiveness of the process (high CCN background) and the larger fraction of graphitic carbon in the air. A paper is being written on this issue.

9. IMGRASS Workshop

Bo-Cai Gao participated the 2nd International Workshop on Inner Mongolia Grassland Atmosphere Surface Studies (IMGRASS) held in Beijing and Inner Mongolia of China between August 25 and 30, 1993, and made a presentation on remote sensing of dust aerosols using ground-based automatic Sun tracking photometers. Joint aerosol measurements of dust aerosols over China among Y. Kaufman, T. Nakajima and Chinese scientists may start as early as spring of 1995.

10. IGAP

A new international activity sponsored by the WMO: IGAP- International Global Aerosol Project was initiated. Y. J. Kaufman chairs the biomass burning aerosol project. A workshop was held in Geneva in June. In the workshop a first draft of IGAP was written. The SCAR experiments are the main biomass burning activity of IGAP.

11. Meetings

MODIS meetings

Yoram Kaufman represented the atmospheric team in most MODIS technical team meetings and in the Ghost meeting. Bo-Cai Gao was on some of the calibration meetings.

Aerosol Topical meeting on remote sensing of aerosol and atmospheric corrections from MODIS and EOS

The meeting was called for by the MODIS team members that are associated with remote sensing of aerosol and atmospheric corrections. The decision to call for the meeting resulted from the need for closer communication and collaboration between scientists developing methods for correction of atmospheric effect over the oceans, correction over the land and remote sensing of aerosol above the ocean and the land. A closer communication with the "outside MODIS" scientific community was also recognized as being needed. Scientists working on AVHRR, MISR, POLDER, EOS-P and Japanese sensors were also invited to review the MODIS activity and report on their developments that can be relevant to the MODIS algorithm development. Scientific managers from NASA / HQR were also invited and took place in the proceedings. The objectives of the meeting were:

- To review the science and algorithms for the analysis of MODIS data for remote sensing of aerosol and for atmospheric corrections.

- To compare and generate a stronger link between the algorithms for correction of atmospheric effects over the oceans and correction over the land.

- To review new methods for remote sensing of aerosol over the oceans and compare them with by-products of atmospheric correction over the oceans.

- To review the algorithms and products anticipated from other sensors available simultaneously with MODIS in order to consider their use in the MODIS activity.

- To review the main unresolved scientific issues regarding remote sensing of aerosol and atmospheric corrections.

- To review the planned activity for validation of the MODIS products.

The meeting was very informative with participation of 30 scientists. A summary of the meeting was submitted to Mike King for the EOS observer.

Status of Recent Publications

Y.J. Kaufman and L. Remer, 1994: ‘Detection of Forested Areas Using the mid-IR on MODIS and AVHRR’, accepted *IEEE J. Geosc. and Rem. Sens.* Jan. 94

Y.J. Kaufman, 1993: 'Measurements of the aerosol optical thickness and the path radiance - implications on aerosol remote sensing and atmospheric corrections', J. Geophys. Res. 98, 2677-2692.

Y.J. Kaufman, A. Gitelson, A. Karnieli, E. Ganor, R.S. Fraser, T. Nakajima, S. Mattoo, B.N. Holben, 1994: 'Size Distribution and Phase Function of Aerosol Particles Retrieved from Sky Brightness Measurements', accepted to JGR-Atmospheres.

Yu. Mekler and Y.J. Kaufman, 1994: ‘On possible causes of calibration degradation of the AVHRR visible and near IR channels’, submitted in Sept. to Applied Optics.

Y.J. Kaufman, B.N. Holben, D. Tanré and D. Ward, 1994: 'Remote sensing of biomass burning in the Amazon', accepted to special issue on remote sensing of the Amazon in Rem. Sens. Rev. Dec 92

Y.J. Kaufman, D. Tanré: 1993: 'Variations in cloud supersaturation and the aerosol indirect effect on climate', submitted in Oct to *Nature*. in revision.