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Validation of algorithms for remote sensing of aerosols over land from the EOS moderate resolution imaging spectroradiometer (MODIS)

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Background.

Apparent reflectance at the top of the atmosphere is very sensitive to the surface reflectance, especially for small aerosol optical thickness. To reduce these uncertainties, algorithms for remote sensing of aerosol, based on concept of dark pixels with surface reflectance $\rho = 0.02+/-0.01$ were developed (Kaufman et al, 1997a, 1997b; see also King et al., 1999). The determination of dark pixels is quite a difficult problem. Kaufman et al, (1997a) suggested to locate the dark pixels using longer wavelengths (2.1 or 3.7 µm) that are less sensitive to aerosol scattering than reflectance in visible range, but sensitive enough to surface characteristics. They have found that reflectance at 2.1 µm is well correlated with reflectance at 0.47 µm and 0.66 µm. Thus, it was suggested to estimate surface reflectance in the visible channels from the 2.1 µm channel reflectance.

Another approach was developed by Wen et al (1999). To avoid using specific values of the relations between mid-IR and visible reflectance, they developed a "path radiance" technique that uses dark object approach to derive optical thickness. It based on the visible and mid-IR reflectance correlation with no assumption about specific values of these relations. The procedure is summarize as follows: (1) construction of linear relation of apparent reflectance between a particular visible band and the mid-IR band using local homogeneous clusters; (2) fit a straight line to the bottom of the envelope of the scatter relation; (3) determine the intercept of the straight line, i.e., the value of the visible radiance for which the mid-IR radiance vanishes.

Justification

Kaufman et al (1997a) have found specific values of relationships between visible and mid-IR reflectance: $\rho_{0.47}/\rho_{2.1} = 0.25$ and $\rho_{0.66}/\rho_{2.1} = 0.5$. However, some studies, Remer (1997), Wen (1999) suggest that it may not hold for all surface types and view angles. Wen et al (1999) noted that the relationship between middle-IR and visible bands (e.g., blue and red) changes with time and varies from one type of vegetation to another, and within certain types of vegetation, as the internal structure of chlorophyll and water amount changes. So, a departure from the "mean relation" may lead to a bias.

Our results show that the ratio $\rho_{0.66}/\rho_{0.47}$ depends on vegetation fraction and density (Gitelson at al., 1996, 2000). The red to blue ratio decreases with increase in density (Fig. 1). The ratio depends also upon vegetation type. For vegetation with high density, the ratio is close to one. For dense irrigated wheat with LAI > 10, the ratio was lowest among species studied. For corn in 1998 and 1999 with the same vegetation fraction and soil brightness but different density (LAI = 3,5-4 in 1999, and not higher than 2.7 in 1998), the ratio primarily depends upon density, decreasing with an increase in density. With a decrease in density and vegetation fraction, the ratio increased, reaching 1.4-2 for vegetation fraction of 10-20 per cent.

When vegetation fraction is moderate to low, the ratio is very dependent on soil brightness, increasing with soil reflectance increase. The highest value of the ratio (more than 2.2) was found for wheat with vegetation fraction lower than 20%. The soil brightness (sand in southern Israel) was the highest among studied. For the same vegetation fraction at around 10-20%, the ratio is much lower for orchards and fields in Central and Northern Israel, and for fields and forest in Germany, where soil reflectance was much lower.

Relationships between ratio of visible reflectance at 0.67 μm and 0.47 μm and mid-reflectance at 2.1 μm are showed for various vegetation types and density (Fig. 2). When reflectance at 2.1 μm was less than 5% (priority 1, Kaufman et al, 1997a), the ratio for wheat was close to 1. When reflectance at 2.1 μm was less than 10% (priority 2), the ratio was around 1.25 for wheat, orchards, and corn. When reflectance at 2.1 μm was less than 15% (priority 4), the ratio reached a maximal value of 1.6 (wheat in Israel) and was lower (1.25 to 1.45) for other types of vegetation. Thus, for each range of 2.1 μm reflectance (priorities 1 to 4), the ratios of mid-IR reflectance to that in the visible spectrum (k = $\rho_{2.1}/\rho_{0.66}$ and m = $\rho_{2.1}/\rho_{0.47}$) were found to be different. It suggests that a-priori information about m and k coefficients is required to estimate properly surface reflectance in the visible channels from the 2.1 μm channel reflectance.

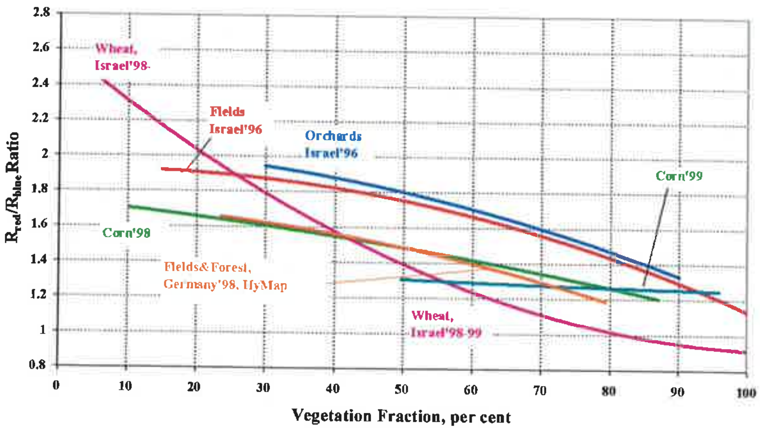

Figure 1.

The red to blue ratio as a function of vegetation fraction. Wheat (Israel'98-99) and corn (Nebraska'98, 99) reflectance spectra have been measured from the height of 2 m above the canopy using close range remote sensing by LI-1800 and SE-590 radiometers, respectively. Spectra of orchards and fields were measured using an ASD radiometer from aircraft (NASA/BGU experiment, Israel'96). Data for agricultural fields and forest spectra were taken in Germany in 1998 by the HyMap system from aircraft.

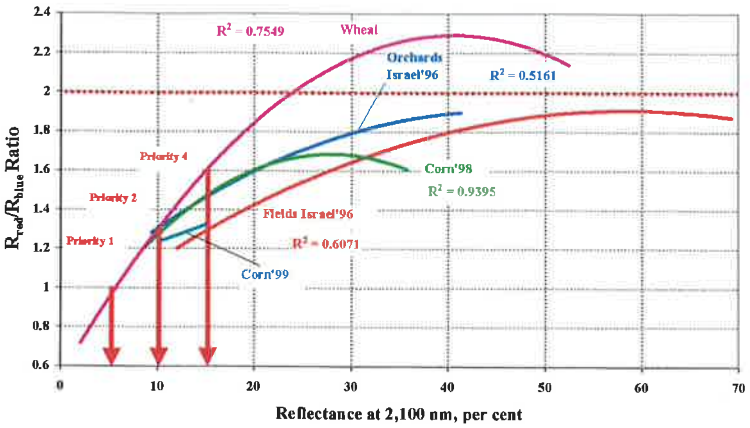

Figure 2.
Red to blue ratio plotted versus reflectance at 2.1 μm.

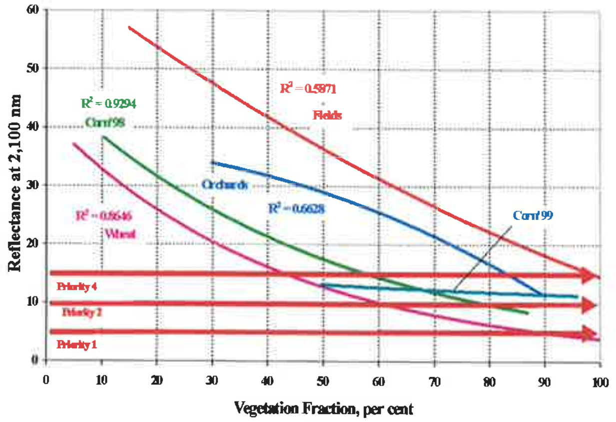

Figure 3. Reflectance at 2.1 μm versus vegetation fraction.

In Fig. 3, priorities are in accord with Kaufman et al (1997a). It can be seen that among species studied, only wheat with vegetation fraction higher than 90% and LAI > 8 meets the priority 1 requirement. Corn with VF > 80%, and wheat with VF > 60% meet the priority 2 requirement. All types of vegetation studied meet priority 3 requirements, when vegetation fraction exceeded 45% for wheat, 50 to 60% for corn and 85% for orchards. Fields in Israel may be used as a dark pixel with priority 4 only when vegetation fraction reaches 100%.

Therefore, for dense vegetation specific values of the ratios $\rho_{0.47}/\rho_{2.1} = 0.25$ and $\rho_{0.66}/\rho_{2.1} = 0.5$ are contrary to understanding of properties of dense vegetation. It was not well validated off nadir or over dense vegetation.

Objectives

1. To find how solid are the assumptions on specific values of the relationships between visible and mid-IR for different agricultural and natural surfaces.
2. To find if the relationships hold for off nadir as function of azimuth and view and sun angle.

3. To find how big are the errors in MODIS optical thickness that are generated due to deviations from the assumptions, how do they depend on view and azimuth angles and surface type.
4. To find if the assumptions can be modified using a third measure, e.g. vegetation index in the mid IR

Approach

We will have the actual instrumentation and measurements of reflectance of natural prairie, row crops, coniferous and deciduous forests in the spectral range from 0.4 to 2.5 μm. We will study relationships between reflectance in MODIS blue, red and mid-IR (2.1 μm) spectral channels for different types of land surfaces.

1. reflectance in nadir and off nadir directions as function of azimuth and view and sun angle in MODIS visible (0.66 μm and 0.47 μm) and 2.1 μm spectral channels will be measured. Relationships between reflectance at 2.1 μm and that at 0.66 μm and 0.47 μm for a wide range of vegetation densities and land covers will be examined. We will find the slope, linearity and intercepts of relationships $\rho_{0.47}/\rho_{2.1}$ and $\rho_{0.66}/\rho_{2.1}$ as well as $\rho_{0.66}/\rho_{0.47}$ for different vegetation fractions and, especially, for different leaf area index when vegetation fraction is high.

2. specific coefficients summarizing the relationships between apparent mid-IR reflectance and visible reflectance at 0.47 and 0.66 μm for each priority (Kaufman et al, 1997a) will be determined. Thus, for each range of mid-IR reflectance (< 0.05; < 0.1, and < 0.15) coefficients $k = \rho_{2.1}/\rho_{0.66}$ and $m = \rho_{2.1}/\rho_{0.47}$ will be found.

3. relationships between $\rho_{2.1}$ and vegetation fraction will be studied; vegetation type and density that meets requirements of a dark pixel will be determined (Example of such an approach is presented in Fig. 3).

To measure reflectance of different vegetation types, the following techniques will be used:

1. ***Goliath,*** designed by Center for Advanced Land Management Information Technologies (CALMIT), University Nebraska-Lincoln, is an all-terrain data-collection platform. The working platform on Goliath is 8 x 9 feet. The hydraulic boom is 11'6" long when stowed, but can be extended to 28 feet during data collection. It can be raised to a height of 32 feet above the ground surface, and rotated through a full circle around the platform. It can be lowered nearly to ground level to accommodate either sensor attachment/adjustments or calibration by means of a reference panel. The operator has complete control of the sensor position from the deck. That is, the sensors can be operated either in nadir or off-nadir positions, and the position can be changed and verified easily and quickly. Although it is possible to operate many different kinds of sensors from the Goliath platform, our primary on-board system for close-range remote-sensing purposes will be an Analytical Spectral Devices (ASD) FieldSpec portable spectroradiometer. The FieldSpec acquires spectral data between 350 and 2500 nanometers in over 2,000 individual narrow bands. The ASD in attached to Goliath in a novel manner; notice that the ASD controller is actually on the boom, while the computer is on the operator platform.

Research targets, such as vegetated surfaces, are photographed from above during the scanning process by means of a remotely operated Kodak digital color-infrared camera system. The targets can also be viewed in real-time by means of an on-board surveillance camera and monitor. Precise location in the field is documented by means of a Trimble real-time global positioning system. All data are georeferenced and stored on the on-board, ruggedized computer.

2. ***A light aircraft*** for aerial photography and airborne hyperspectral data collection with Analytical Spectral Device (ASD), Kodak IR digital camera, and color digital video camera will be used for data collection. The current airplane configuration allows both of the imaging devices to be paired and the ASD can also be manually triggered to acquire data along with the cameras. Real-time differentially corrected GPS allows navigation to study site as well as logging of the flight path.
A mount will be developed to allow off-nadir viewing while the aircraft is in straight-and-level flight. When the aircraft is in straight-and-level flight the desired target is more easily attainable in the field of view. This allows multiple viewing angles (0°, 15°, 30°, 45°, and 60°) of approximately the same targets, which can be changed in flight.

Optical thickness of the atmosphere will be measured in several places concurrently with aircraft measurements.

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Budget
Pilot project

ITEM	Direct	Benefits	Indirect	Total
Programmer (0.5, MS level)	16,000	3,680	8,758	28,438
Graduate Research Assistant	12,500	2,875	5,729	21,104
Part-time technicians (100 hrs @ 7.00/hr)	700		312	1,012
Aircraft Surveys- (20 hrs @ 300/hr)	6,000		2,670	8,670
Computer Useage	3,000		1,320	4,320
Travel - Research	3,500		1,558	5,058
Total	**41,700**	**6,555**	**20,347**	**68,602**

Budget Justification

One senior **Graduate Research Assistant** (GRA) will serve as **Project Data Manager** (reporting to Gitelson & Rundquist). This GRA will be responsible for radiometric data collection in the field, and from aircraft. He will be responsible for project documentation.

Programmer (reporting to Gitelson) will develop software for pre-processing, classification, and further processing data obtained by means of hyper spectral radiometry in the fields, from aircraft, and also by imaging spectrometers from aircraft. He will also develop a database of radiometric data.

A **Student Hourly Technician** (reporting to Gitelson & Rundquist) will be responsible for maintenance of hardware for close range and aircraft radiometric measurements.

Computer/equipment costs include use of existing computers and peripherals for image classification, GIS analysis, plotting, and CD-ROM generation. Both operation and hardware/software maintenance are included. The standard rate charged by CALMIT is $35/hour.

Supplies and materials costs include costs for purchasing satellite image data from the USGS/EROS Data Center and from NASA. These costs also cover maps, aerial photography, and digital geospatial data not currently on-hand at UNL.

Aircraft Survey costs includes use of the UNL aircraft and sensors for collecting hyperspectral and image data. The standard rate charged by UNL is $300/hour.

Travel costs include expenses for field data collection in Nebraska, anticipated travel to the GFSC/NASA (Washington, D.C.).

Indirect costs are computed as 44.5% of Total Direct Costs minus 20% of graduate students salaries dedicated to tuition remission.