A Review of Atmospheric Correction Techniques for Hyperspectral Remote Sensing of Land Surfaces and Ocean Color

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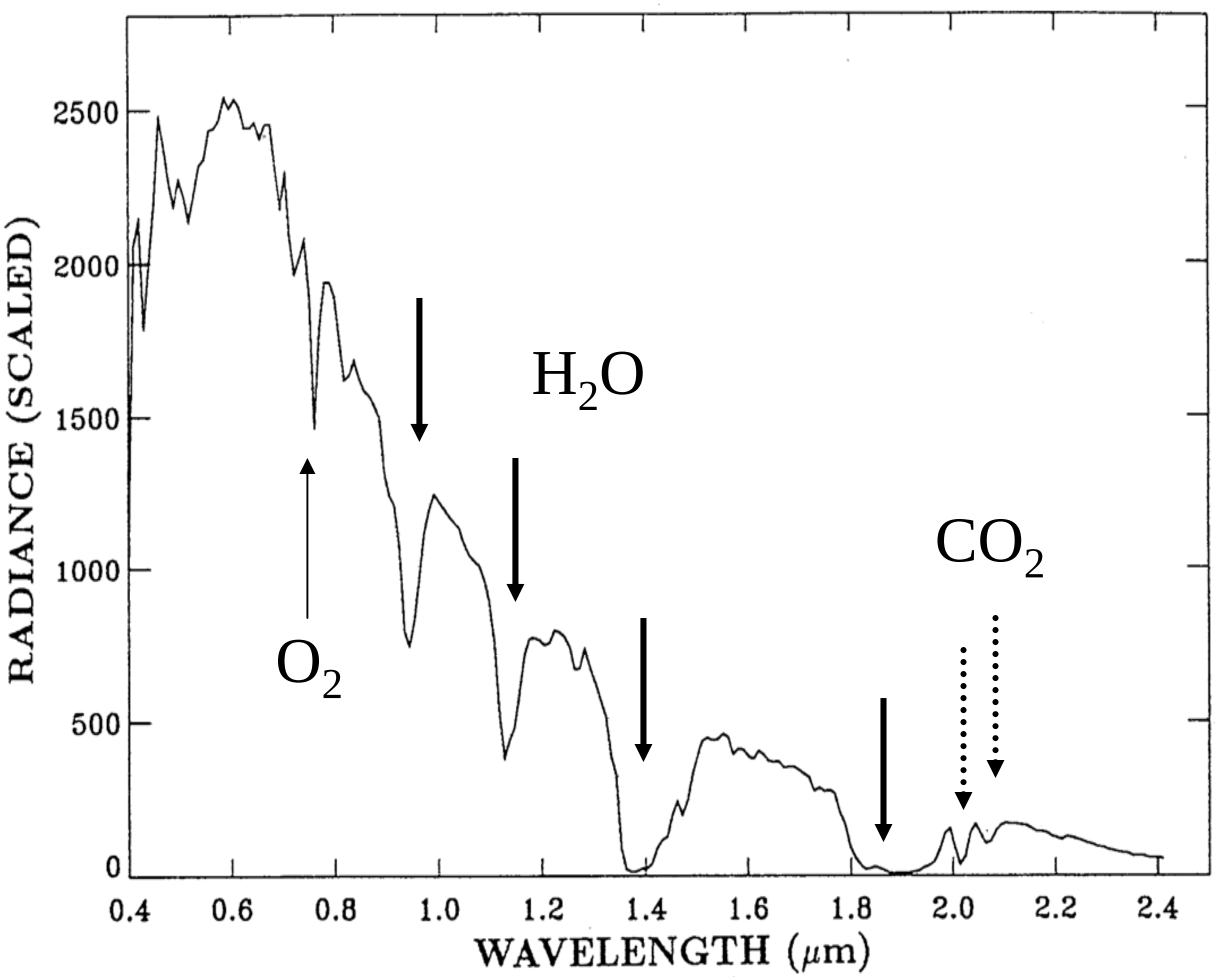
OUTLINE

- In this presentation, I will give a brief review on atmospheric correction techniques. Basically, the techniques can be grouped as:
  - Scene-based empirical approaches
  - Radiative transfer modeling approaches
  - Hybrid approaches, which are combinations of radiative transfer modeling and empirical approaches
- I will discuss issues related to spectral smoothing.
- I will also suggest possible future improvements to the present algorithms – addition of modules for NO_2 absorption and cirrus corrections.

A SAMPLE AVIRIS SPECTRUM



The AVIRIS spectrum is affected by atmospheric absorption and scattering effects. In order to obtain the surface reflectance spectrum, the atmospheric effects need to be removed.

Scene-based Empirical Approaches

- During the mid-1980s, several empirical approaches were developed.

- The “***internal average reflectance***” (IAR) approach (Kruse) calculates the average spectrum of a scene. The spectrum of any pixel in the scene is then divided by the average spectrum to estimate the relative reflectance spectrum for the pixel.

- The “**flat field**” approach assumes there is an area in the scene that has spectrally neutral reflectances with little wavelength dependences. The mean spectrum of the “flat field” is then used for the derivation of relative reflectance spectra of other pixels.

- The derived relative reflectance spectra with both techniques often contain unrealistic absorption features.

Scene-based Empirical Approaches

- The **empirical line approach** requires field-measurements of reflectance spectra for at least one bright target and one dark target.
- The imaging spectrometer data over the surface targets are linearly regressed against the field-measured spectra to derive the gain and offset curves.
- The gain and offset curves are then applied to the whole scene.
- This method produces spectra that are most comparable to reflectance spectra measured in the fields or laboratories.
- It should be pointed out that all the empirical approaches can be applied to imaging spectrometer data without absolute radiometric calibrations. However, the imaging system should be stable during data acquisitions.

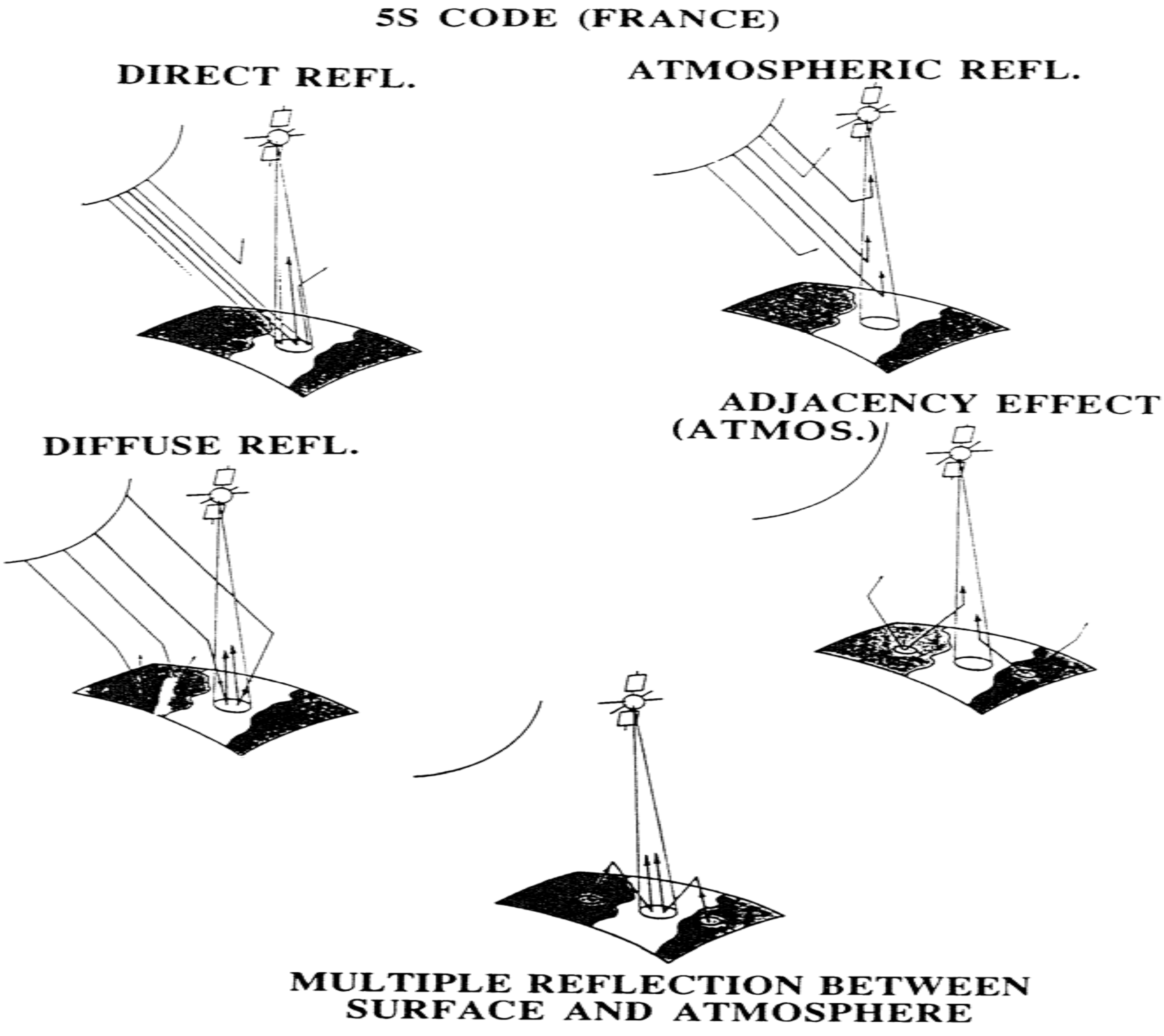
Radiative Transfer Modeling Approaches

- Around 1987, Alex Goetz perceived the needs of developing an atmospheric correction technique using radiative transfer modeling approaches.

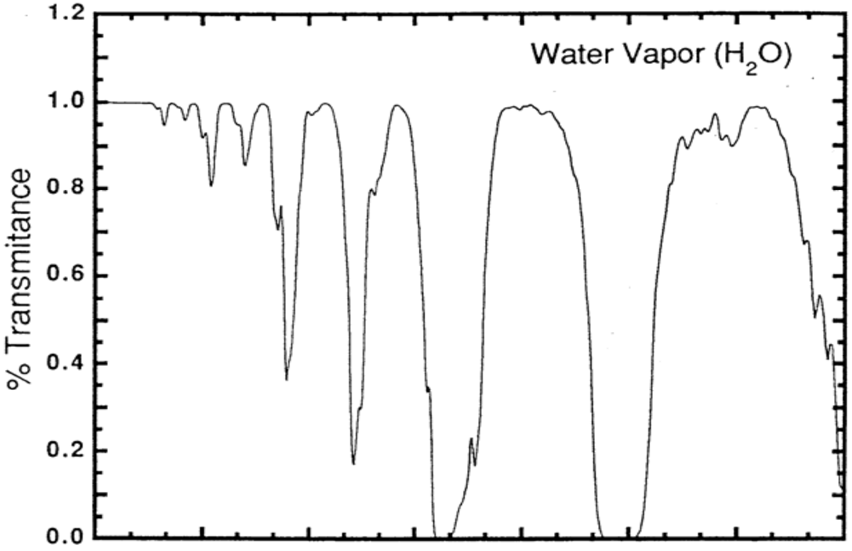
- This requires explicit modeling of absorption and scattering effects of atmospheric gases and aerosols.

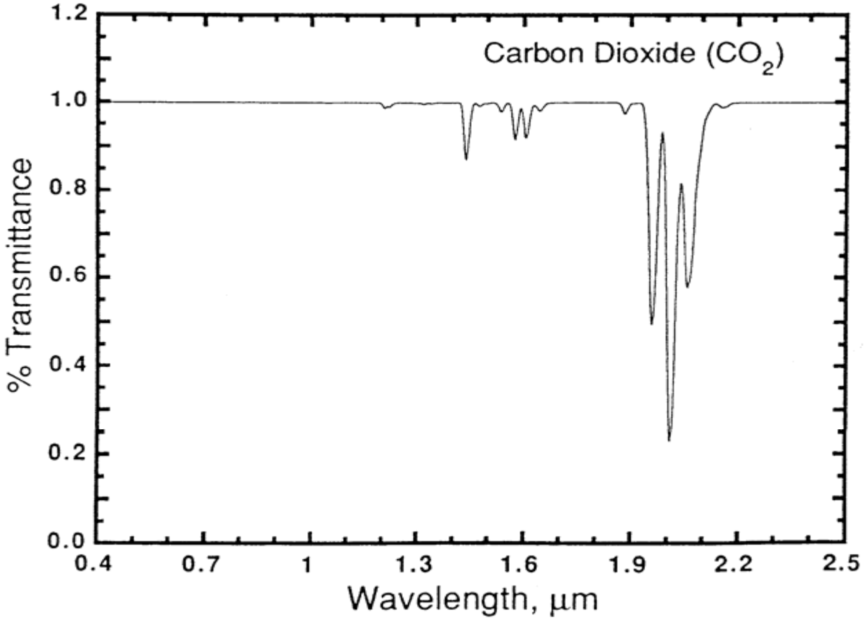
- We started the algorithm development in 1988. At the time, we used the 5S code to model atmospheric scattering effects, and the Malkmus band model to simulate gaseous absorption effects.

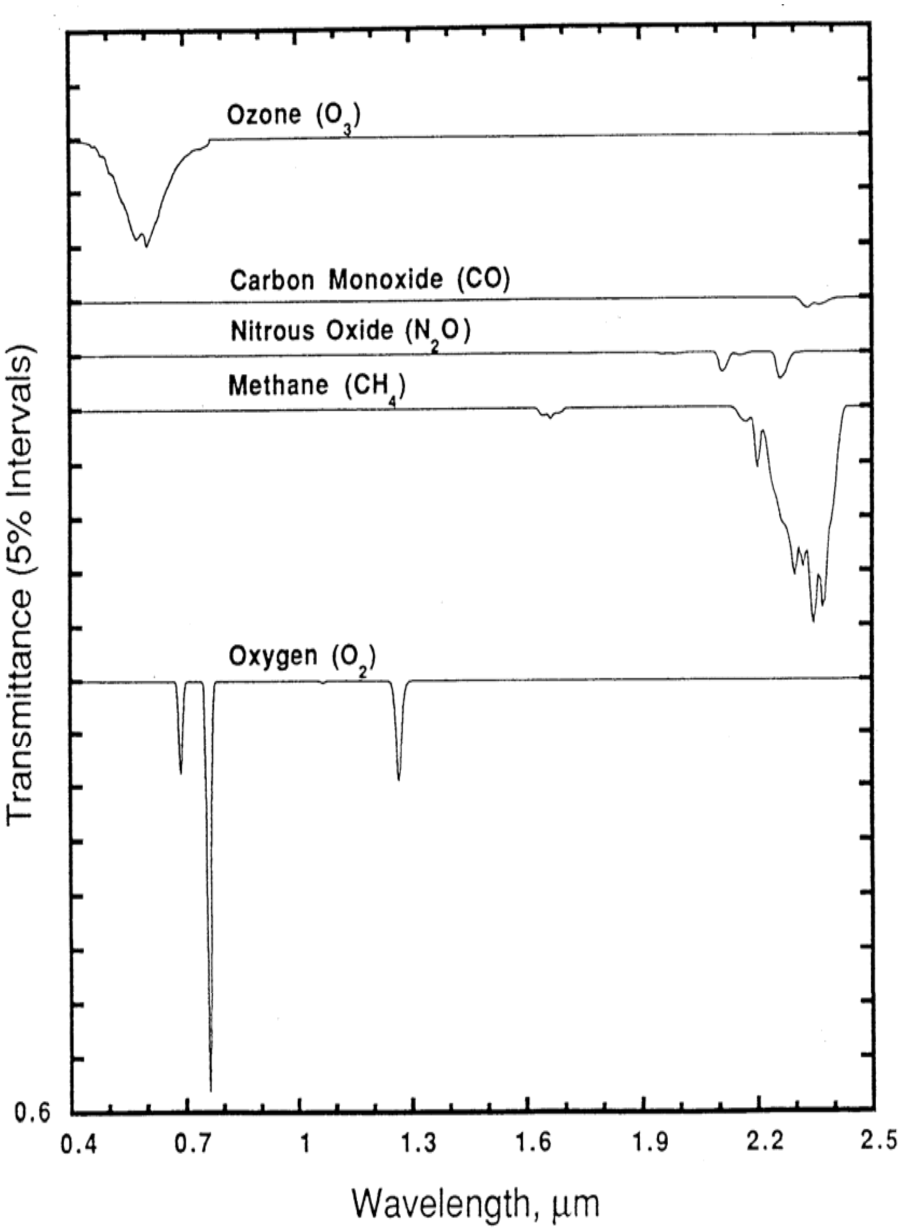
Illustration of Different Radiation Components (D. Tanre)



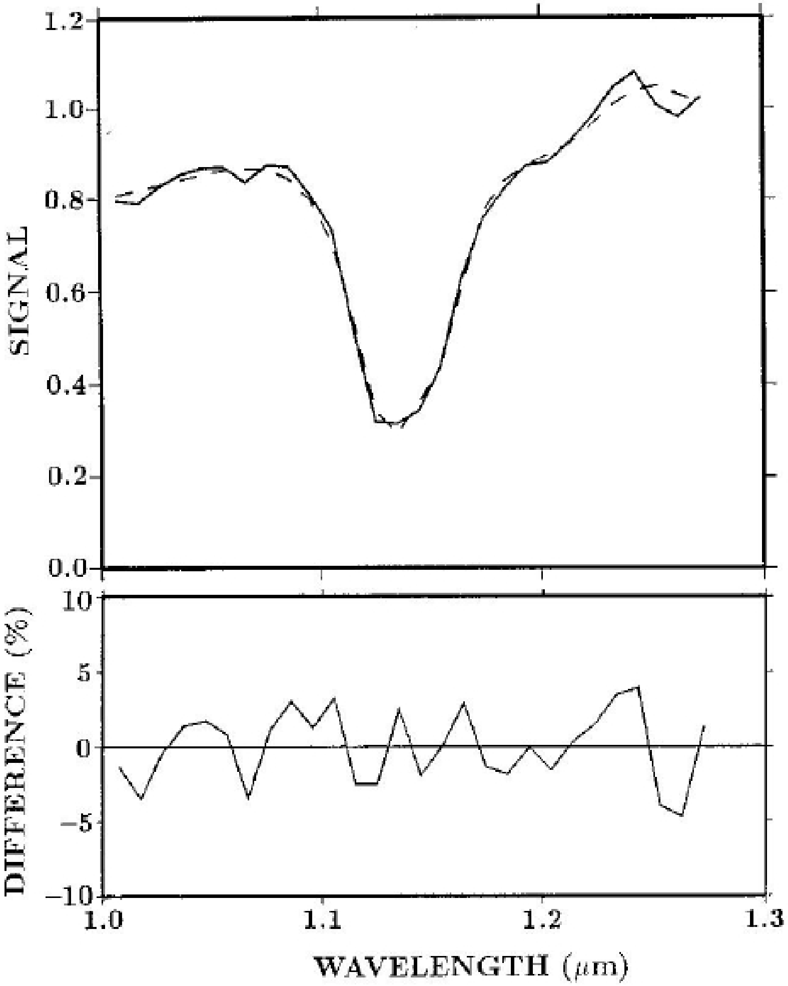
Transmittance Spectra of H_2O, CO_2, O_3, N_2O, CO, CH_4, & N_2O

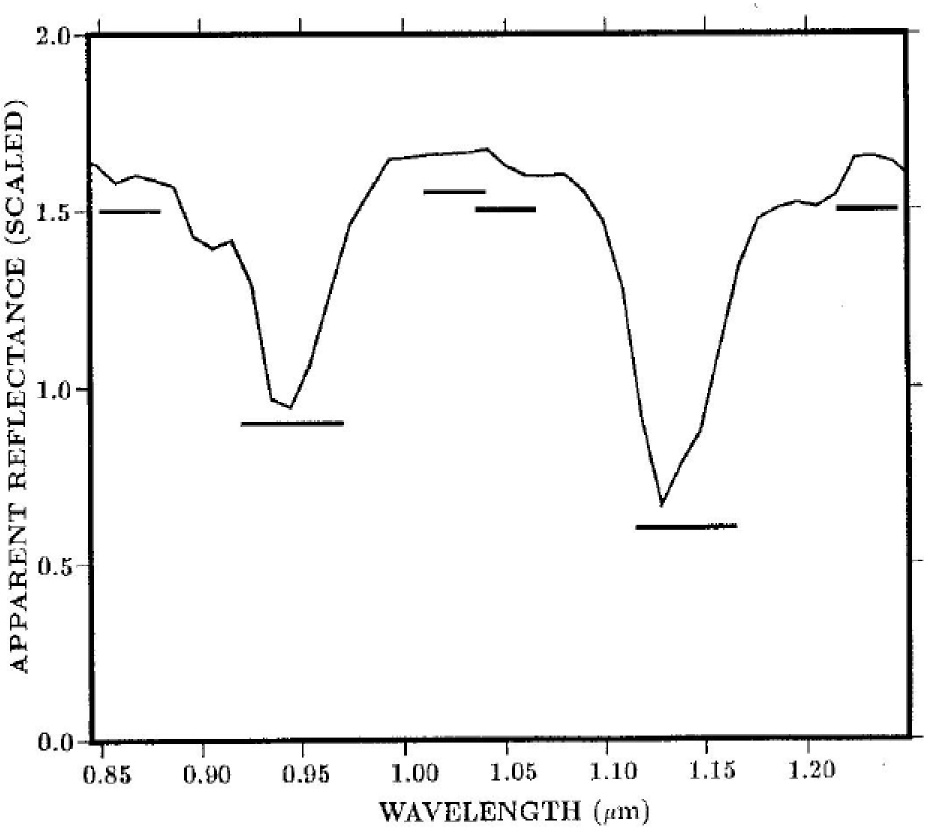




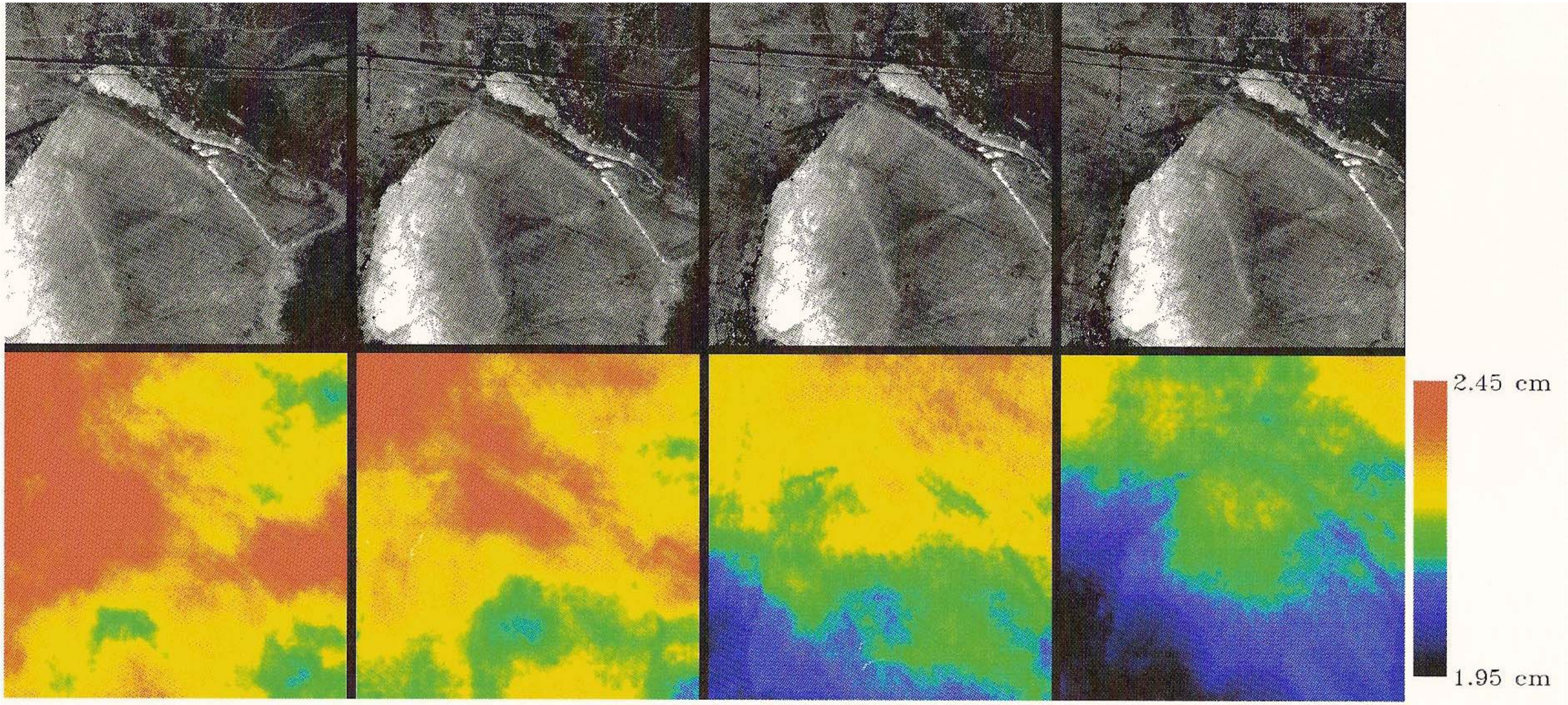


Water Vapor Retrievals Using Spectrum-Matching & Channel Ratio Techniques

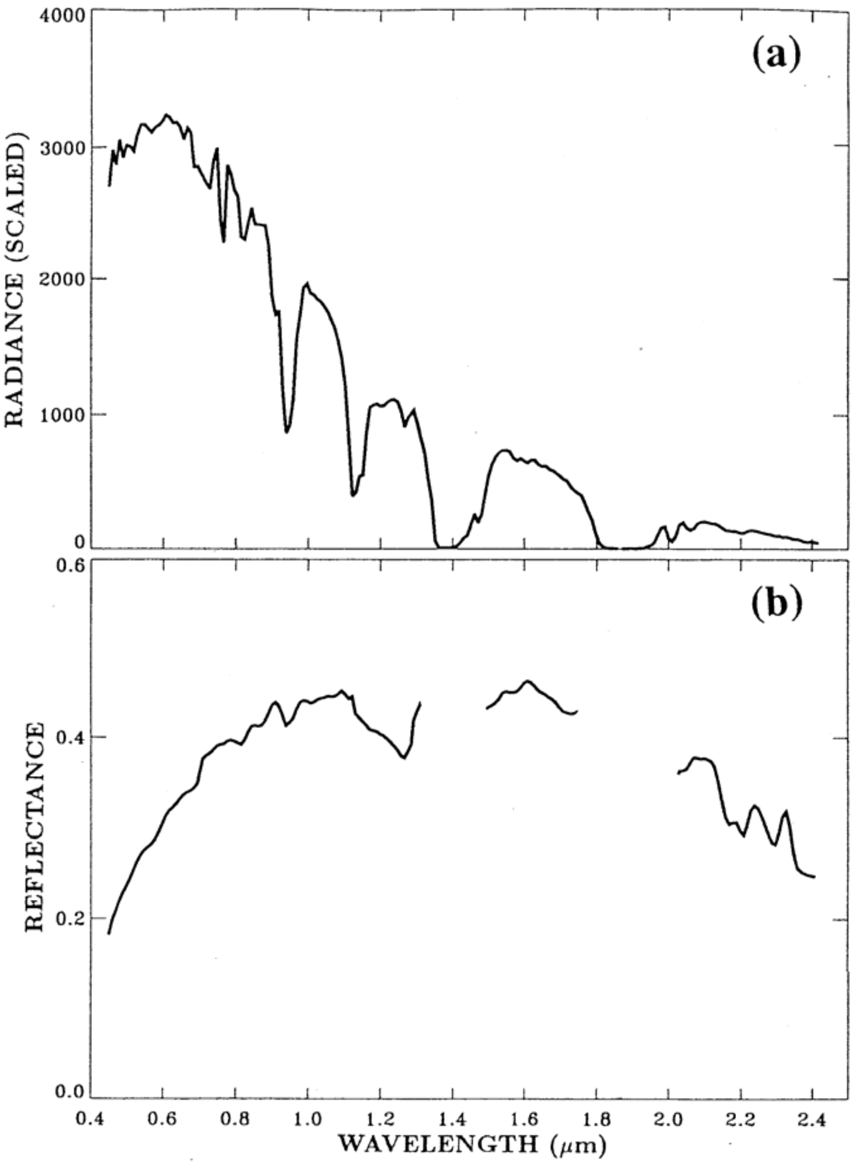


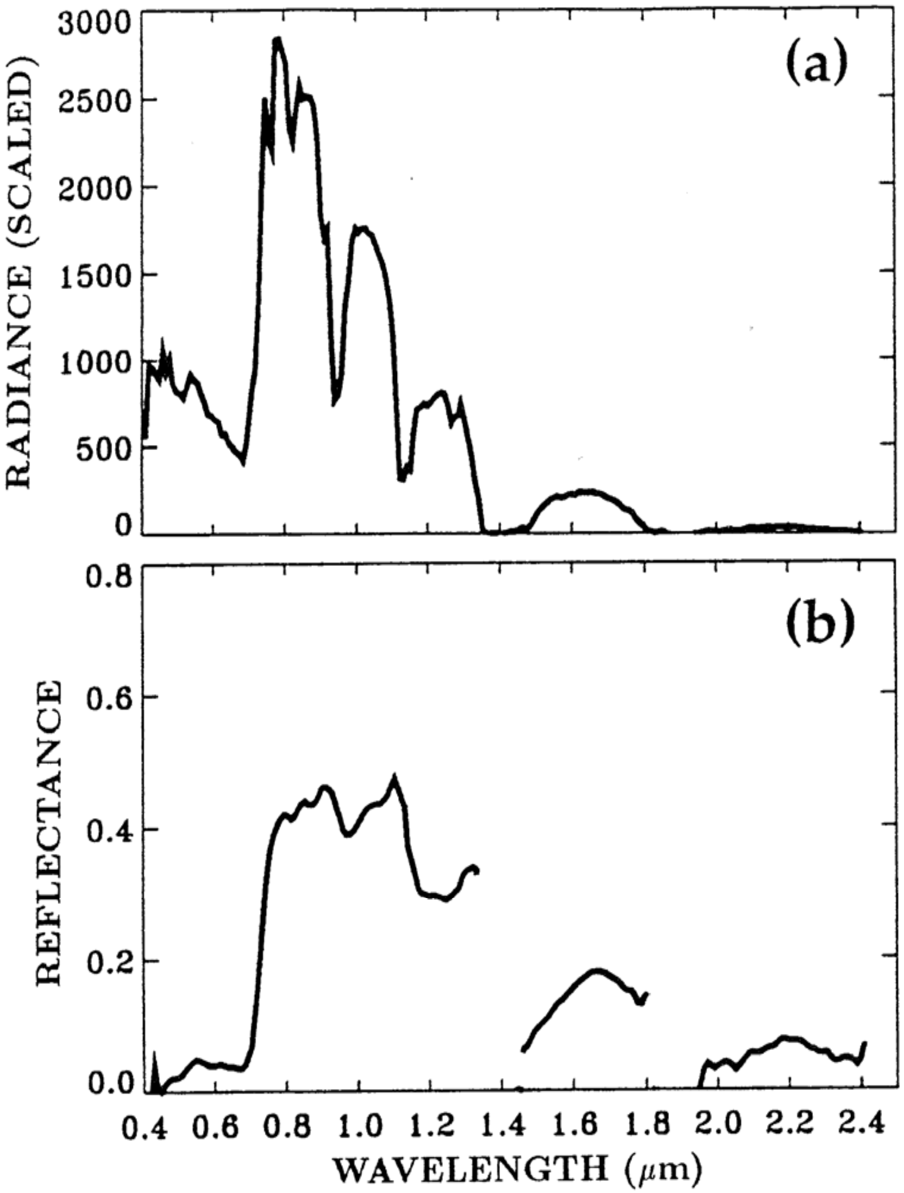


SAMPLE WATER VAPOR IMAGES



SAMPLE REFLECTANCE RETRIEVALS WITH ATREM

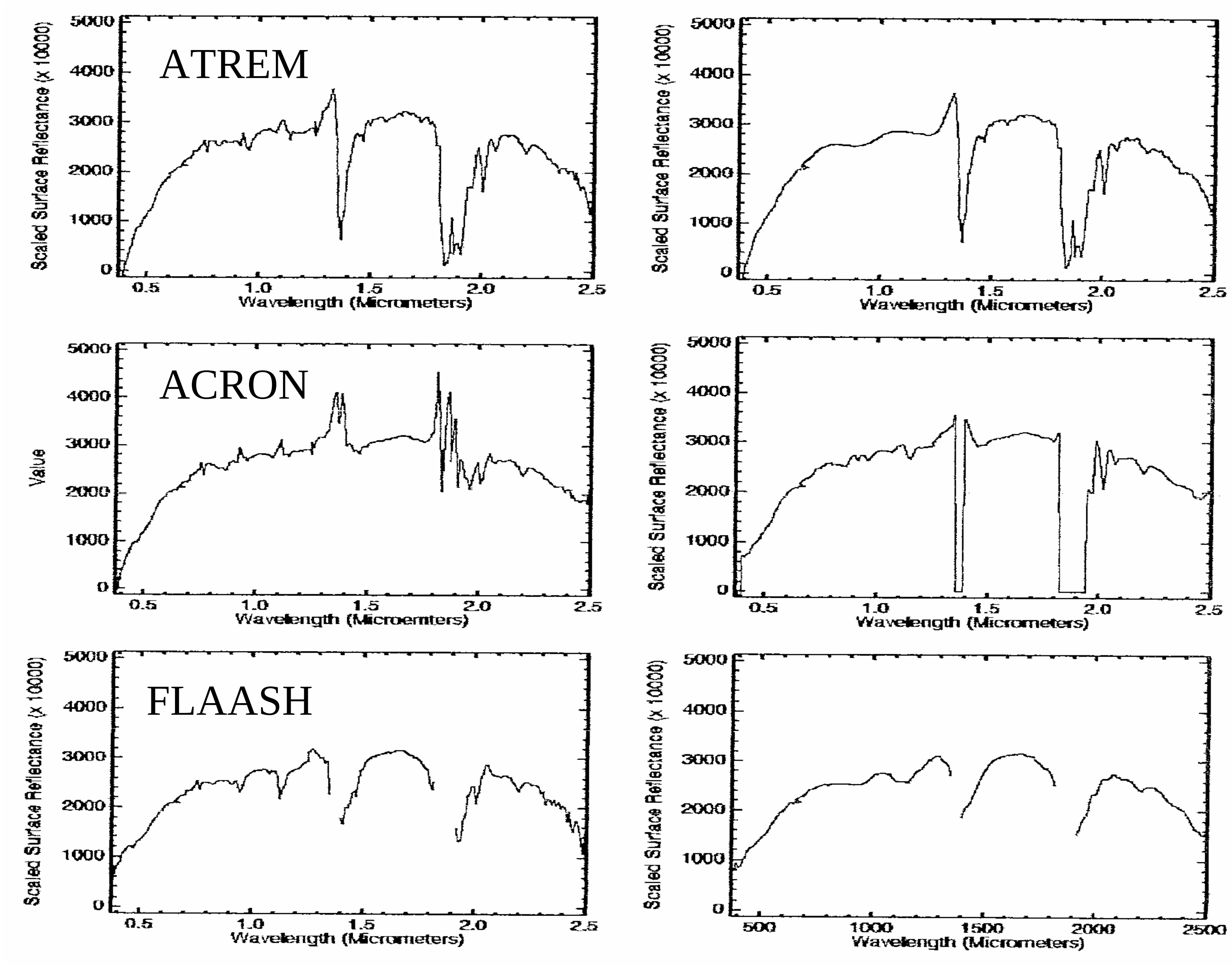




A List of Several Atmospheric Correction Algorithms

- ATREM – uses 6S code for scattering, Malkmus band model for gas transmittance calculations, band ratio, no adjacency effect correction, disabled smoothing routine before releasing for public use.
- HATCH – self-written multi-scattering routine, correlated k-distribution method for gas transmittances, “smoothness test”, automatic spectral calibration, no adjacency correction.
- FLAASH – MODTRAN4 for multiple scattering and gas transmittance calculations, with smoothing routine and adjacency effect correction.
- ACRON – MODTRAN3 for multiple scattering and gas transmittance calculations, with smoothing routine.
- ATCOR – Several versions of ATCOR codes, lookup tables based on MODTRAN4, handles rugged terrain effects.

Comparison of Results from ATREM, ACRON, & FLAASH (F. Kruse)



Comparison of Results from FLAASH, ACRON, and Field Measurement
(P. A. Rochford et al. TGRS, December 2005)

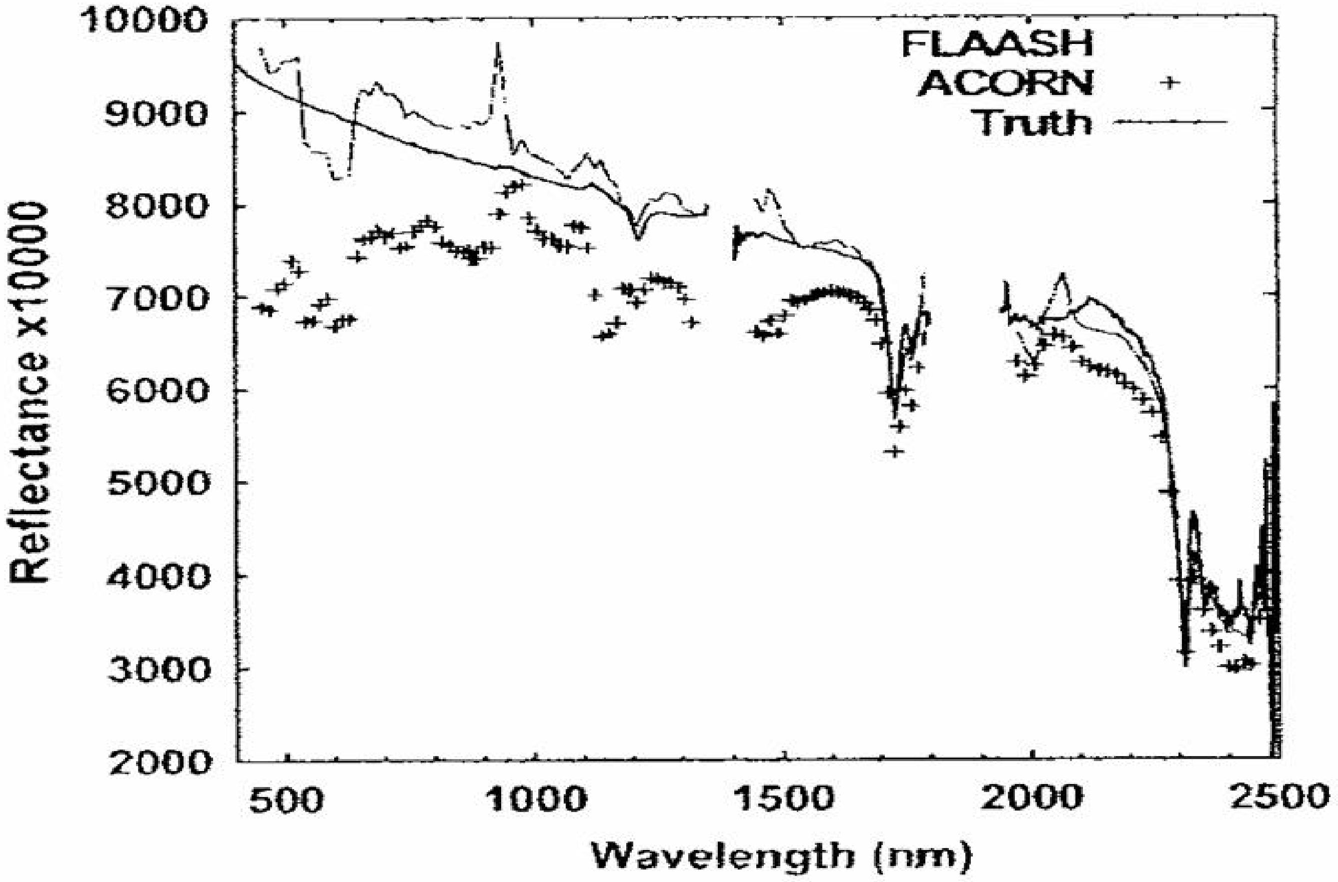


Fig. 4. Default retrievals from FLAASH and ACORN from HyMap image 2 for the large white tarp. The bite-outs below 625 nm are due to saturation of the sensor.

Hybrid Approaches

- Hybrid approaches use combinations of radiative transfer modeling and empirical approaches.

- For example, R. Clark et al. used a combination of ATREM and field spectral measurements over a single ground calibration site. The use of ATREM allows improved atmospheric corrections at elevations that are different from the calibration site, while the ground calibration removes residual errors commonly associated with radiative transfer models.

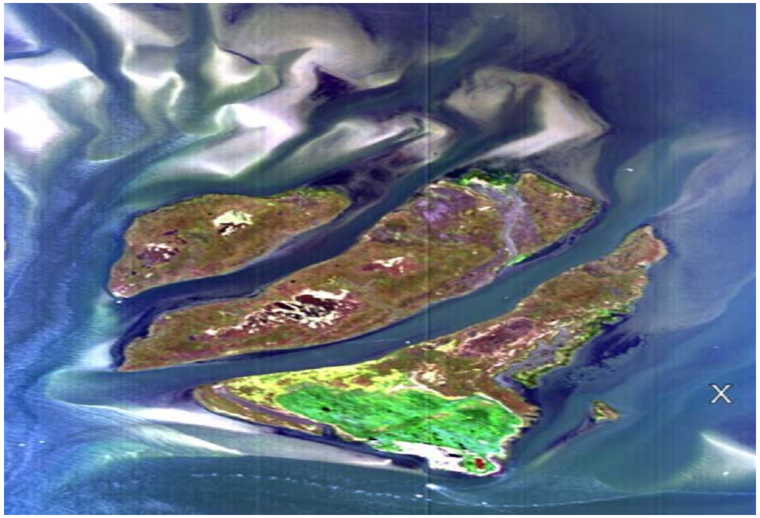
- An excellent description of the technique can be found at:
  http://speclab.cr.usgs.gov

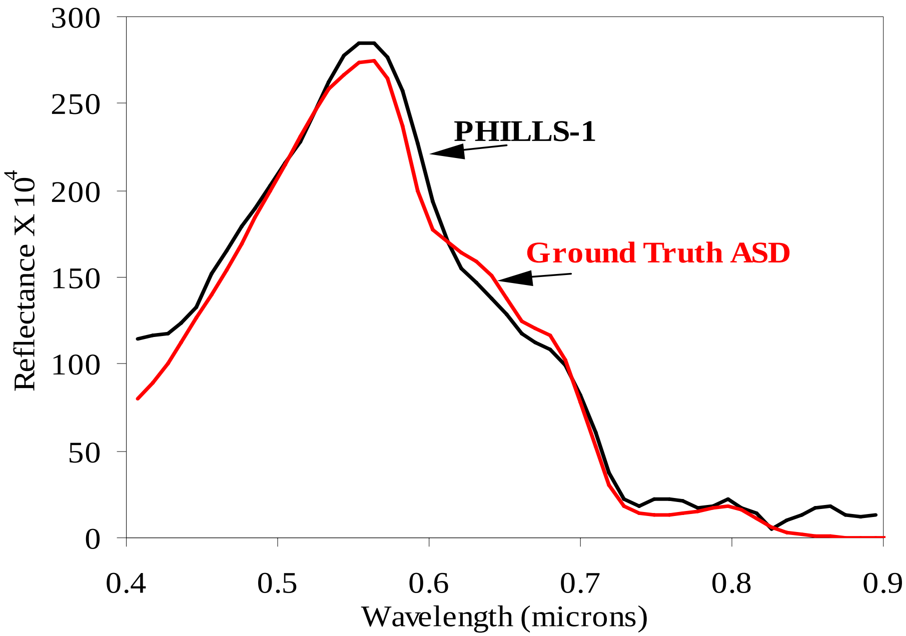
Atmospheric Corrections Over Ocean

- A small research community is interested in hyperspectral remote sensing of ocean color.

- We have developed an atmospheric correction algorithm for ocean applications.

- The algorithm used a vector radiative transfer code for the generation of lookup tables, and handled the specular reflection at the air/water interface.





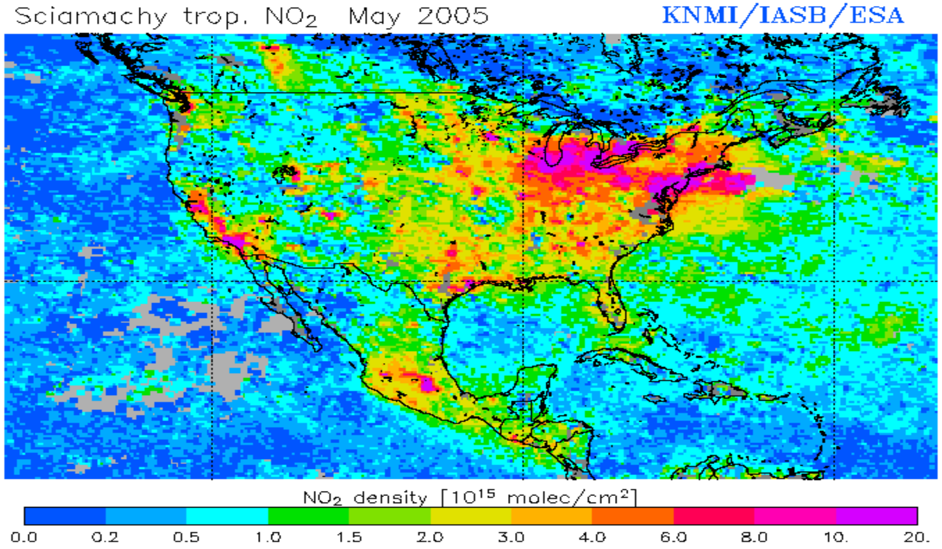
Comments on Spectral Smoothing

- Several algorithms have built-in routines to smooth the output reflectance spectra on a pixel-by-pixel basis.

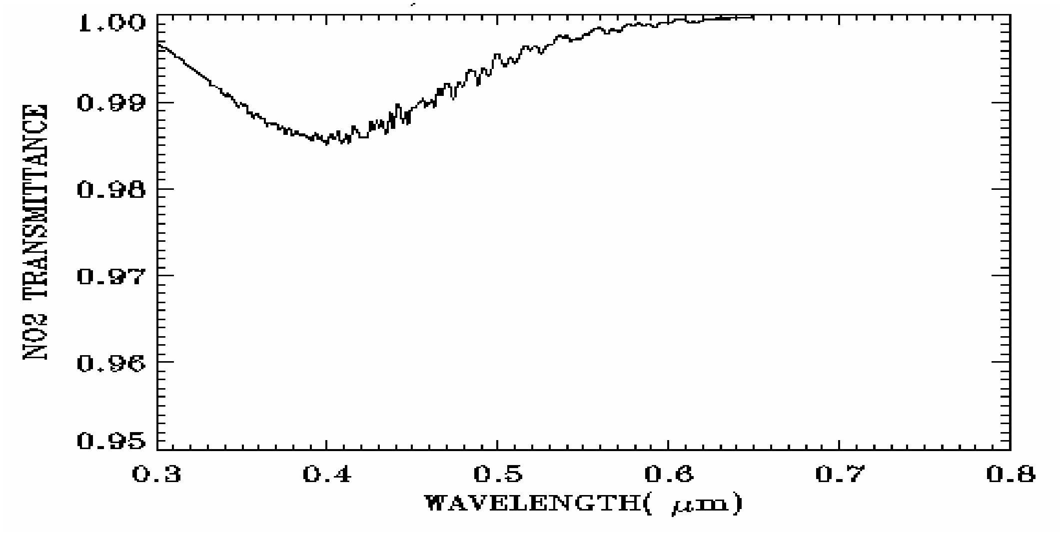
- Therefore, different gain curves are applied to different pixels.

- A common gain curve to all pixels in a scene is no longer present after such smoothing. It is not a good idea to derive another gain curve based on field-measured reflectance spectrum and then apply the curve to all pixels in a scene.

Atmospheric NO_2 Absorption



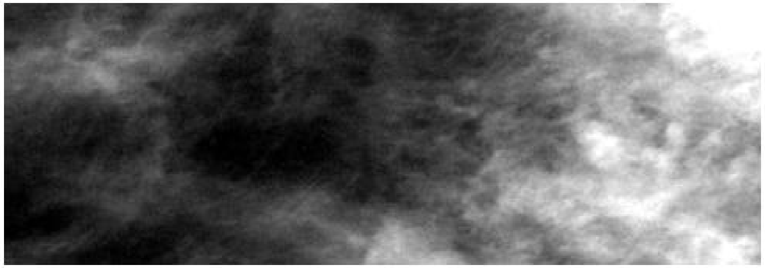
An NO2 Transmittance Spectrum



- Column NO_2 amount maps are now routinely available based on European satellite measurements.
- Enhanced NO_2 concentrations are observed in some geographical regions in certain months.
- NO_2 absorption should be included in future updated atmospheric correction algorithms.

Cirrus Corrections

0.65 µm Image
(Un-corrected)



1.38 µm Image

0.65 µm Image
(Cirrus-Corrected)

- In the past, aerosol corrections received most of the attention.
- Thin cirrus clouds occur quite frequently. It is possible to detect and correct for thin cirrus effects from imaging spectrometer data.
- Just like aerosol corrections, thin cirrus effects need to be removed in order to derive accurately the surface reflectance spectra from imaging spectrometer data.

This concludes my main presentation…

Now a few personal remarks on Alex Goetz.

A few personal remarks on Alex Goetz

- I had the opportunity to work with Alex from 1988 to 1992. Alex is the first person who had the insight on the needs of a radiative transfer based atmospheric correction algorithm. He hired me through the NOAA/CERES Visiting Fellow program to do the job.

- Alex vigorously defended the HIRIS program in the late 1980s and early 1990s. At the time, the NASA EOS community thought HIRIS was a "*geology-only*" instrument. In order to change the perception of the EOS community, Alex used every opportunities to promote our work on remote sensing of water vapor and cirrus clouds with AVIRIS. This laid the solid foundation for the later implementation of near-IR channels on MODIS for remote sensing of water vapor and cirrus clouds.

Column Atmospheric Water Vapor and Vegetation Liquid Water Retrievals From Airborne Imaging Spectrometer Data

BO-CAI GAO AND ALEXANDER F. H. GOETZ

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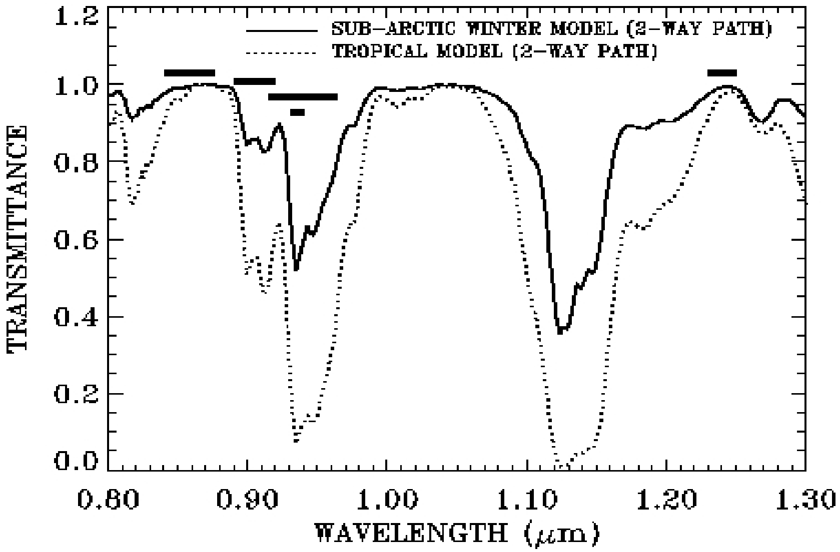
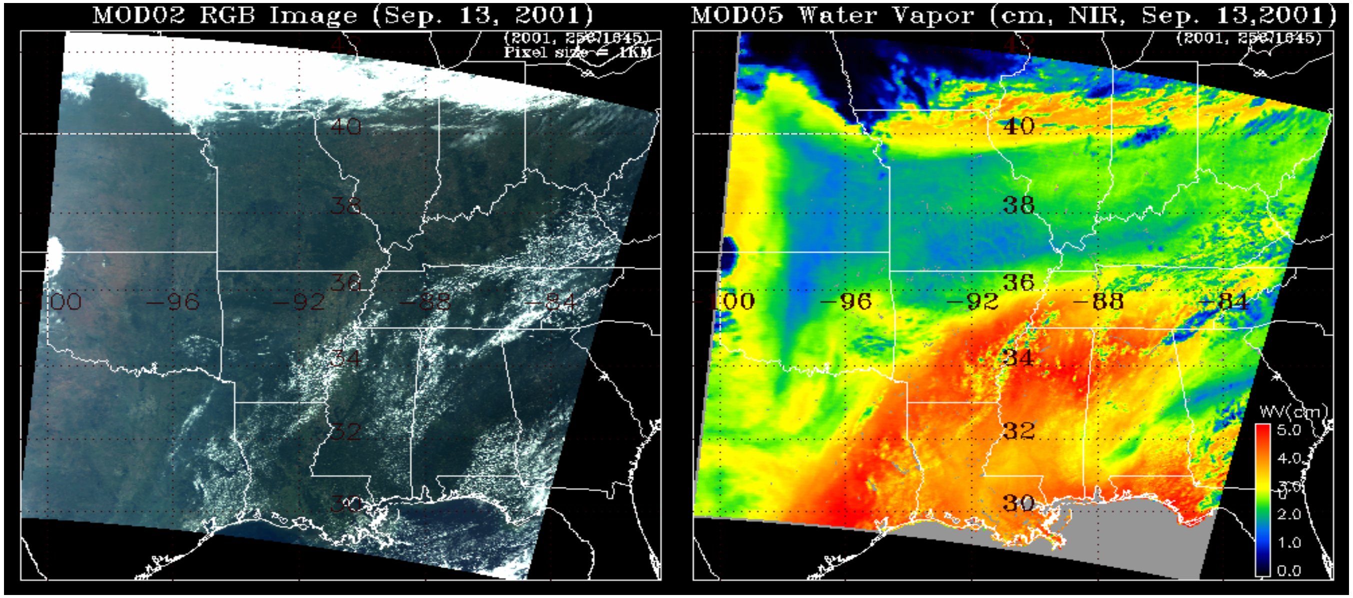
University of Colorado, Boulder

High spatial resolution column atmospheric water vapor amounts were derived from spectral data collected by the airborne visible-infrared imaging spectrometer (AVIRIS), which covers the spectral region from 0.4 to 2.5 μm in 10-nm bands and has a ground instantaneous field of view of 20x20 m from an altitude of 20 km. The quantitative derivation is made by curve fitting observed spectra with calculated spectra in the 1.14-μm and 0.94-μm water vapor band absorption regions using an atmospheric model, a narrow-band spectral model, and a nonlinear least squares fitting technique. The derivation makes use of the facts that (1) the reflectances of many ground targets vary approximately linearly with wavelength in the 0.94- and 1.14-μm water vapor band absorption regions, (2) the scattered radiation near 1 μm is small compared with the directly reflected radiation when the atmospheric aerosol concentrations are low, and (3) the scattered radiation in the lower part of the atmosphere is subjected to the water vapor absorption. The technique is directly applicable for retrieving column water vapor amounts from AVIRIS spectra measured on clear days with visibilities 20 km or greater. The precision of the retrieved column water vapor amounts from several data sets is 5% or better. Based on the analyses of an AVIRIS data set that was acquired within an hour of radiosonde launch, it appears that the accuracy approaches the precision. The derived column water vapor amounts are independent of the absolute surface reflectances. It now appears feasible to derive high spatial resolution column water vapor amounts over land areas from satellite altitude with the proposed high resolution imaging spectrometer (HIRIS). Curve fitting of spectra near 1 μm from areas covered with vegetation, using an atmospheric model and a simplified vegetation reflectance model, indicates that both the amount of atmospheric water vapor and the moisture content of vegetation can be retrieved simultaneously because the band centers of liquid water in vegetation and the atmospheric water vapor are offset by approximately 0.05 μm.

For this 1990 JGR paper, Alex and I had made at least 3 major revisions before submitting it to JGR for publication. The paper has become a classical paper on remote sensing of water vapor using near-IR channels. So far, it has more than 90 citations.

MODIS near-IR Water Vapor Channels & Retrievals





CIRRUS CLOUD DETECTION FROM AIRBORNE IMAGING SPECTROMETER DATA USING THE 1.38 μm WATER VAPOR BAND

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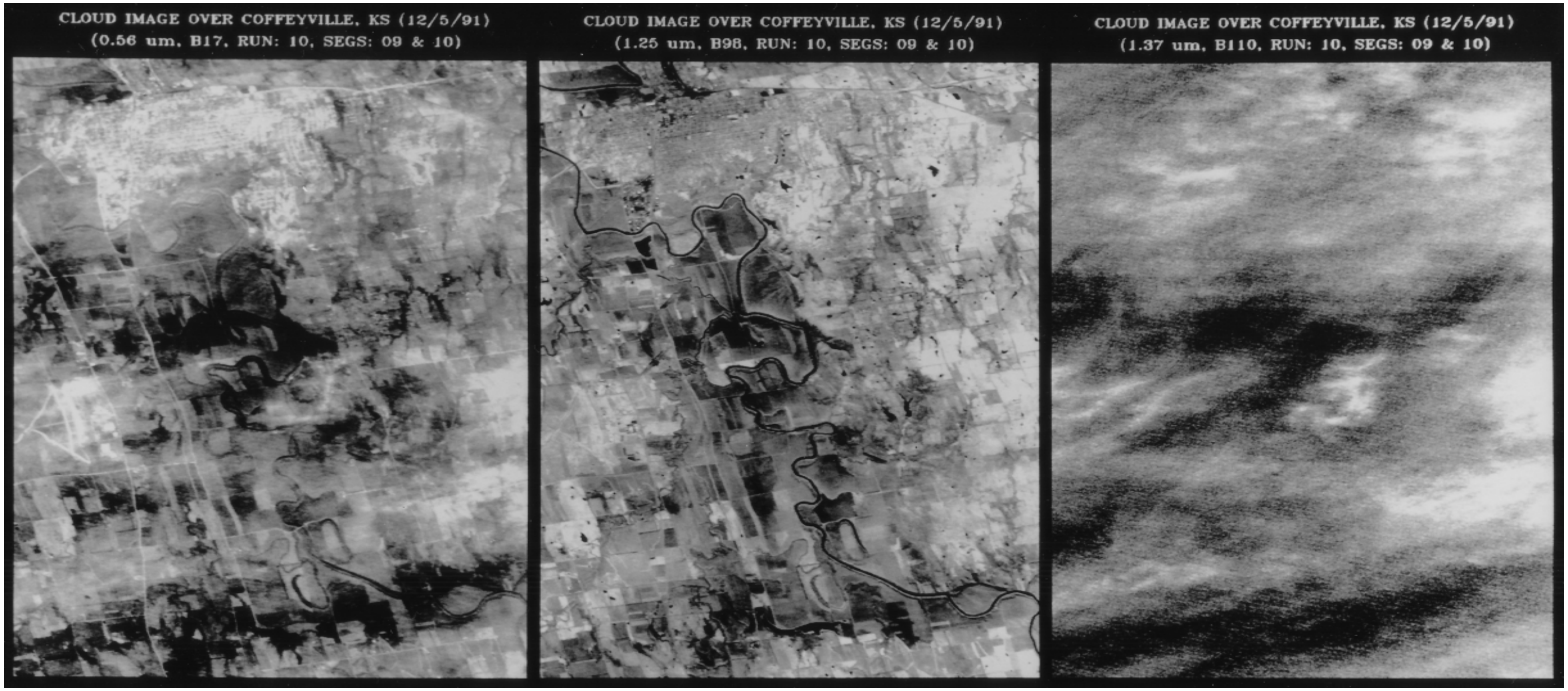
Warren J. Wiscombe
Climate and Radiation Branch, NASA Goddard Space Flight Center

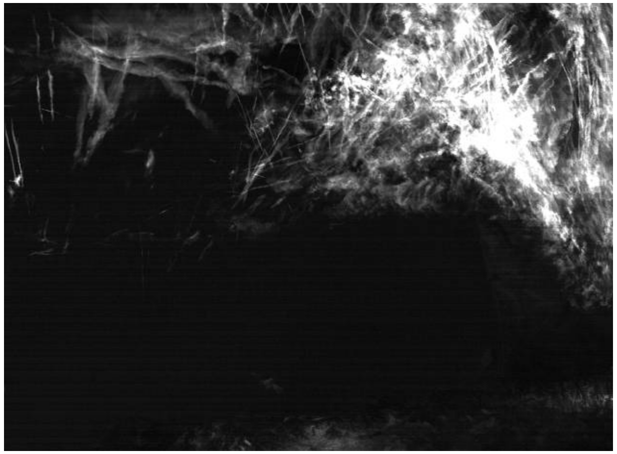
Abstract. Thin cirrus clouds are difficult to detect, particularly over land, in images taken from current satellite platforms. Using spectral images acquired by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) at 20 km altitude, we show that wavelengths close to the center of the strong 1.38 μm water vapor band are useful for detecting thin cirrus clouds. The detection makes use of the fact that cirrus clouds are located above almost all the atmospheric water vapor. Because of the strong water vapor absorption in the lower atmosphere, AVIRIS channels near 1.38 μm receive little scattered solar radiance from the surface or low level clouds. When cirrus clouds are present, however, these channels receive large amounts of scattered solar radiance from the cirrus clouds. Our ability to determine cirrus cloud cover using space-based remote sensing will be improved if channels near the center of the 1.38 μm water vapor band are added to future satellites.

This 1993 GRL paper described the technique for cirrus detections using the 1.38-μm channel. We used the AVIRIS data collected during the FIRE Phase II field experiment for demonstration purposes. Before the experiment, Alex Goetz, Jeff Dozier, and Diane Wickland made necessary financial arrangements for flying AVIRIS during the FIRE II experiment. With the high quality AVIRIS data, we were able to convince the NASA MODIS Project to implement a similar channel on MODIS for cirrus detections.

Examples of Cirrus Detections with AVIRIS & MODIS




MODIS Original RGB Image


1.38-μm MODIS Image


Cirrus-Corrected Image

Thank you, Alex!!!

Enjoy life after retirement!!!