USING GROUND SPECTRAL IRRADIANCE FOR MODEL CORRECTION OF AVIRIS DATA

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1. Introduction

Over the last decade a series of techniques has been developed to correct hyperspectral imaging sensor data to apparent surface reflectance. The techniques range from the empirical line method (Conel et al, 1987) that makes use of ground target measurements to model-based methods such as ATREM (Gao et al, 1993) that derive parameters from the data themselves to convert radiance to reflectance, and combinations of the above (Clark et al, 1995). Here we describe a technique that combines ground measurements of spectral irradiance with existing radiative transfer models to derive the model equivalent of an empirical line method correction without the need for uniform ground targets of different reflectance.

2. Background

Hyperspectral imaging, with sensors such as AVIRIS, raises the expectation among novice users that a complete reflectance spectrum of the surface can be obtained after atmospheric correction. While this is a reasonable expectation, the reality is that extensive ground calibration at the time of overflight is necessary to derive the proper correction. The correction involves both an additive and a multiplicative term as seen in equation 1.

$$L_\lambda = \frac{\rho_\lambda T_\lambda E_\lambda \cos\theta}{\pi} + L_{p\lambda} \qquad (1)$$

$$\rho_\lambda = \frac{\pi\left(L_\lambda - L_{p\lambda}\right)}{T_\lambda E_\lambda \cos\theta} \qquad (2)$$

where ρ is the reflectance, E is the exoatmospheric solar irradiance, T is the atmospheric transmission and L_p is the path radiance, all a function of wavelength. The angle between the surface normal and the sun is θ. The reflectance is called "apparent reflectance" because of the uncertainty of the surface attitude (Gao et al, 1993). For simplicity, lambertian scattering from the surface is assumed.

A universally used technique that characterizes both the gain or transmission and the offset or path radiance is called the empirical line method (Conel et al, 1987). It consists of acquiring field reflectance spectra of a bright and dark target in the field, preferably large enough to encompass several pixels. A regression equation is created for each spectral band that provides a relationship between reflectance and raw radiance data. The result is a gain factor that consolidates all the multiplicative influences such as atmospheric transmission, solar irradiance and instrument response as well as an offset that is related to the sensor and the path radiance. The quality of the correction depends heavily on the availability of uniform ground targets of differing albedos located close together.

For the last decade, researchers have been concentrating on developing model-based techniques that derive all the necessary parameters from the image data themselves. These techniques rely on absolute radiometric calibration of the sensor and accurate knowledge of the exoatmospheric solar irradiance. The first attempt to make a rapid pixel by pixel correction (Gao and Goetz, 1990) only accounted for atmospheric transmission associated with water vapor. Later the ATMospheric REMoval Program (ATREM) was developed to account for other atmospheric gases and path radiance (Gao et al, 1993). Green et al (1996) applied the radiative transfer code MODTRAN-3 (Berk et al, 1989; Anderson et al, 1996) to correct for both transmission and path radiance. However, this technique is very computing intensive.

A combination of ATREM and the empirical line method was used successfully by Clark et al (1995) to correct the errors in ATREM by calculating the normalization factors for one pixel and then applying them to the rest of the ATREM-corrected image. While this solves the problem of errors in the model, it still requires well-understood, uniform calibration targets that are normally only found in desert environments.

The following is a description of a potential method, using a surface irradiance measurement at the time of overflight, that can be used to anchor a radiative transfer model for the sun-surface path to calculate the surface - sensor path transmission and scattering components.

3. Technique

3.1 Initial AVIRIS Comparison

The technique relies on determining atmospheric parameters from the spectral irradiance measurements made at the surface which in turn drive the MODTRAN model (Berk et al, 1989) to provide an at-sensor modeled radiance. In our first attempt, an ASD FieldSpec™-FR spectroradiometer (www.asdi.com), covering the region 350-2500 nm was used in the irradiance mode to receive sunlight with a remote cosine receptor. The irradiance spectra were acquired on June 28, 1996, 14:53 GMT at Harvard Forest, MA coincident with an AVIRIS overflight. The data were acquired in a grassy field and subsequently surface reflectance measurements were made with the same instrument. Figure 1 shows the relative coincidence of the irradiance spectra measured and modeled with MODTRAN. The general mismatch short of 600 nm is most likely the result of an improper scattering assumption. The major spikes in the ratio spectrum occur around deep atmospheric absorption features and are possibly the result of improper spectral calibration. The FieldSpec-FR has a wavelength calibration accuracy of ±1 nm.

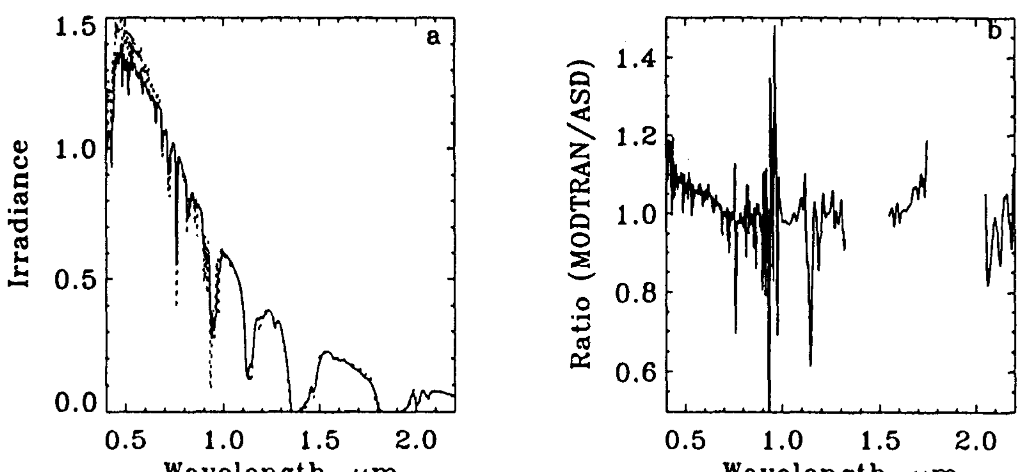

Fig. 1. Measured surface irradiance together with the nearest MODTRAN model (a). The figure (b) is a plot of the ratio between the MODTRAN model and the measured surface irradiance.

Figure 2 shows the surface reflectance derived from ATREM. Figure 3 shows the modeled MODTRAN radiance at AVIRIS altitude using parameters derived from the measured surface irradiance. The resulting reflectance spectrum of the 10-pixel grassy field closely matches the ground measured spectrum. The mismatch short of 600 nm comes from the fact that the scattering term was not correctly derived from the ground spectral irradiance measurements.

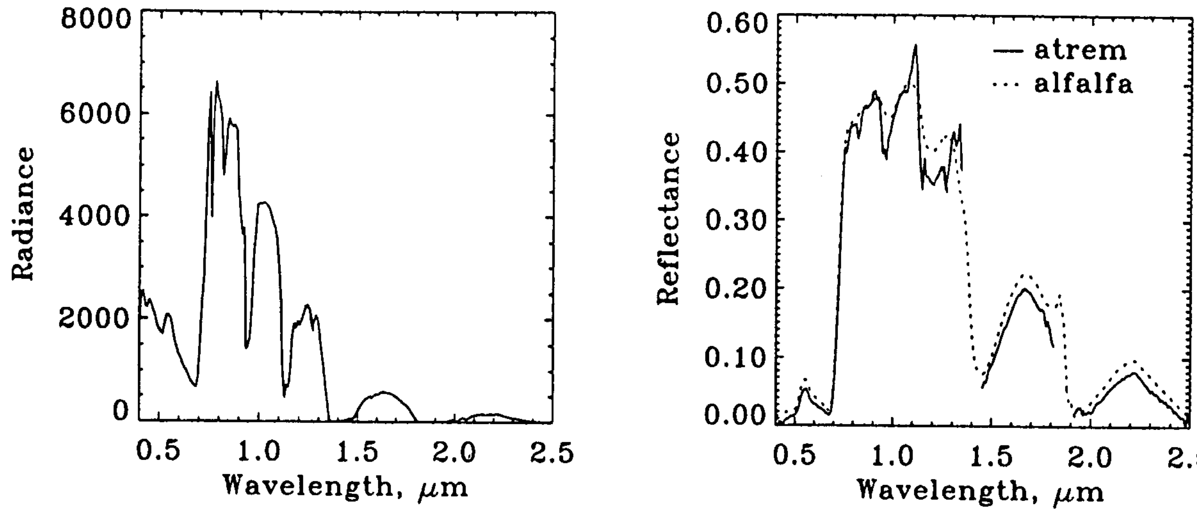

Fig 2. On the left is a plot of the average radiance received by AVIRIS from a group of 10 pixels over a vegetated field in Harvard Forest, MA. The right figure is a reflectance plot derived from ATREM.

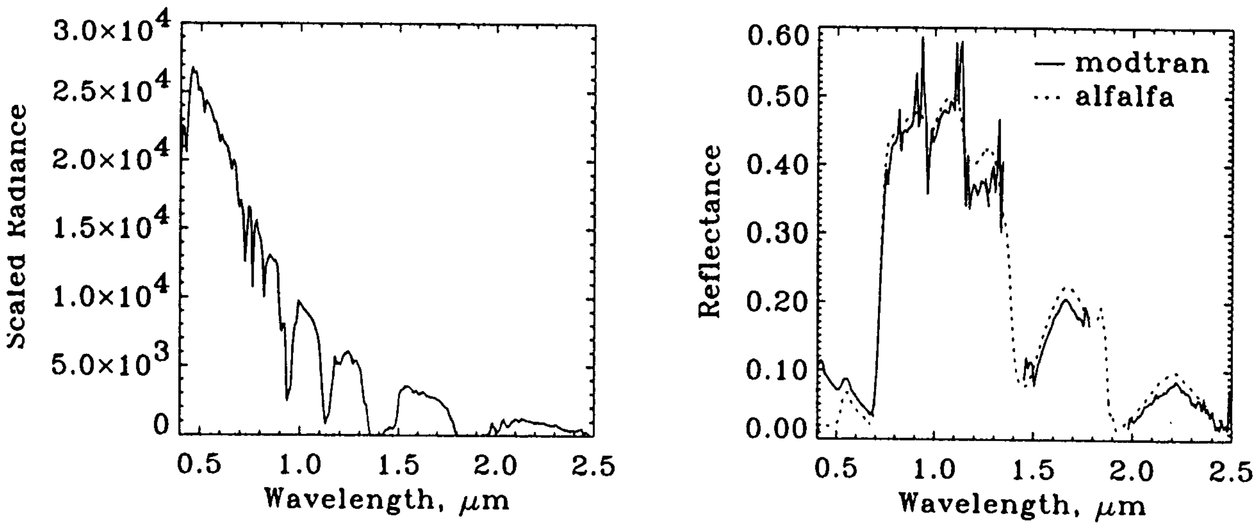

Fig. 3. On the left is the modeled radiance at AVIRIS altitude derived from MODTRAN and the measured surface irradiance. On the right is the reflectance derived from the model and superimposed is the field-measured spectral reflectance from an average taken over the 10-pixel field site. Scattering has not been accounted for, hence the disagreement in the visible region.

3.2 Radiance Databases

The initial attempts to find a MODTRAN model that would match the irradiance spectrum demonstrated that, for practical application, a method for rapid searching was required. Since multiple calculations of a radiative transfer code are too time consuming for pixel-by-pixel corrections, we decided to predetermine a multidimensional lookup table that relates atmospheric parameters to the image pixel radiance spectra. For this purpose, we developed two data bases, the first a set of measured irradiance spectra that includes over 8000 spectra acquired in the summer of 1997 in Boulder, Colorado under a variety of atmospheric conditions. The second data base consists of a series of 13,200 MODTRAN models incorporating combinations of variations in six parameters; zenith angle, water vapor, aerosol, cloud model, visibility and atmosphere profile. The parameters used are given in Table 1. The question remained whether the MODTRAN database represented actual atmospheric conditions.

Table 1: MODTRAN database parameters

ATMOSPHERE PROFILE	WATER VAPOR PROFILE	AEROSOL PROFILE	CLOUD PROFILE	VISIBILITY (km)	ZENITH ANGLE
tropical	tropical	rural	no clouds	5	0
mid-latitude summer	mid-latitude summer	maritime	cumulus	15	36.9
mid-latitude winter	mid-latitude winter	urban	stratus	23	60
subarctic summer	subarctic summer	desert	stratocumulus	50	72.5
subarctic winter	subarctic winter		standard cirrus model	100	84.3
1976 US Standard	1976 US Standard		sub-visual cirrus model		

3.3 Parameterization

The measured and modeled databases were resampled to AVIRIS resolution. A principal components transformation of each database reveals similarity in the dimensionality (fig. 4). Plots of individual eigenvectors show that beyond the first principal component the eigenvectors differ significantly (fig. 5). Mapping the intersection of subspaces revealed that the two data sets share a 10-dimensional spectral space (fig. 6) and that one can be transformed into the other. This property makes it possible to search for a model equivalent to an irradiance measurement rapidly and subsequently use the model parameters to calculate the surface-sensor atmospheric path corrections. Principal components transformation of the intersecting databases shows that the eigenvectors up to the 8th component are nearly identical, as seen in figure 7 and as predicted in figure 4.

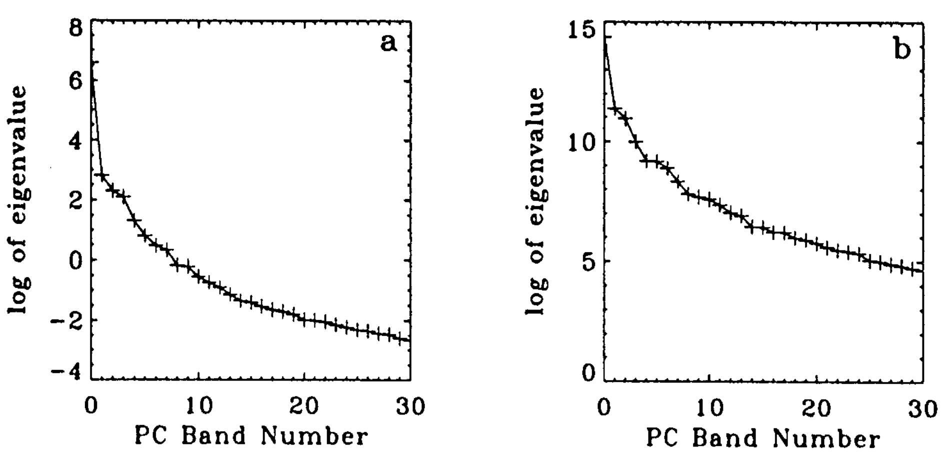

Fig. 4. Eigenvalue plot of the suite of field-measured irradiance spectra (a) and the MODTRAN database spectra (b).

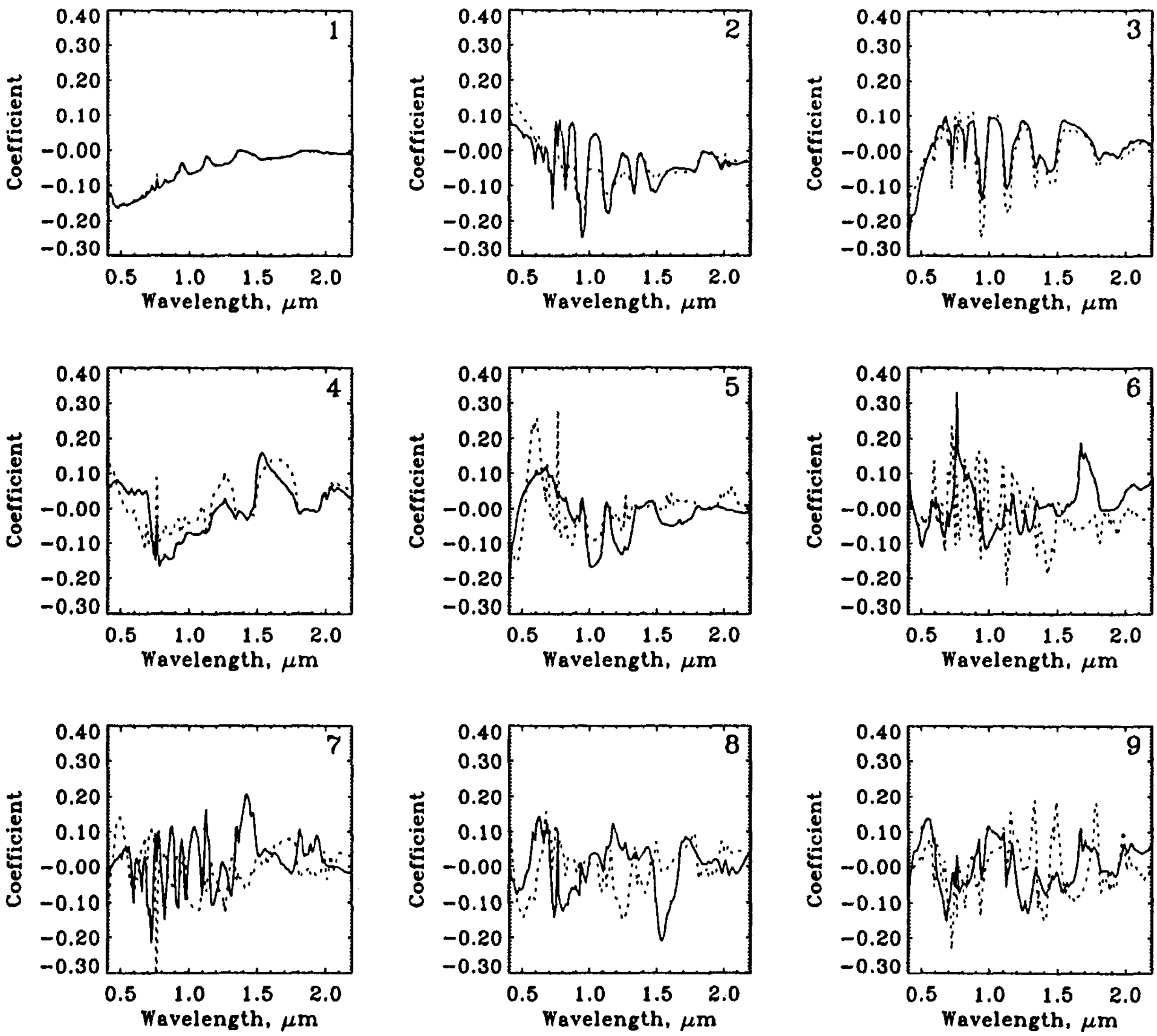

Fig. 5. Nine eigenvectors from the principal component transformation of the measured irradiance spectra (solid line) and the MODTRAN spectra (dashed line)

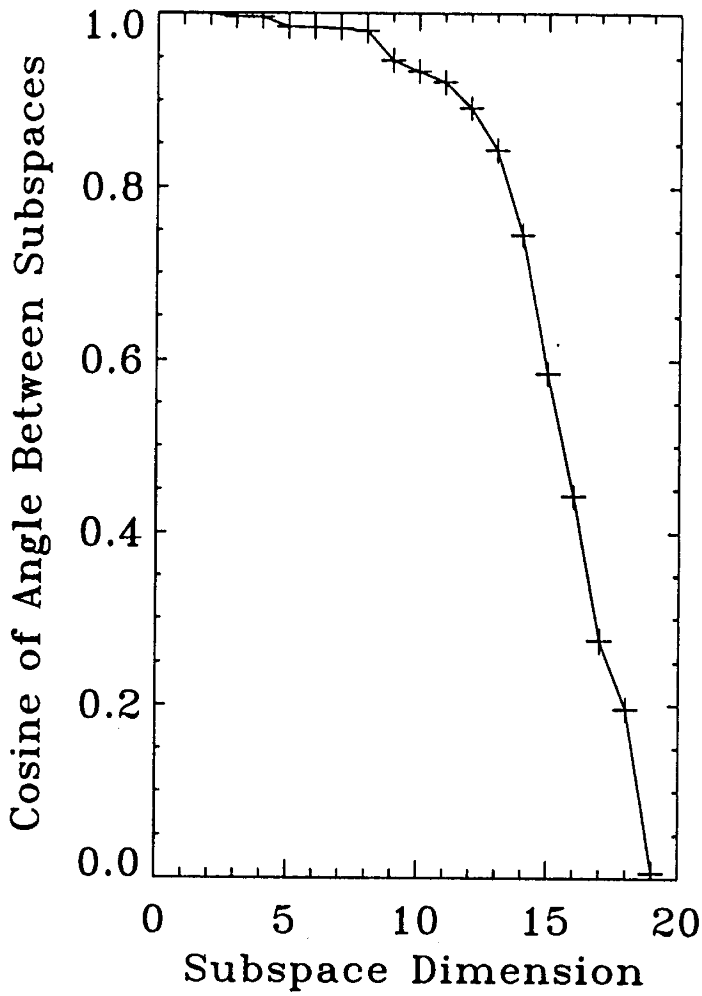

Fig. 6. The quality of match or overlap in 20 space of the irradiance and MODTRAN databases as measured by the angle between subspaces.

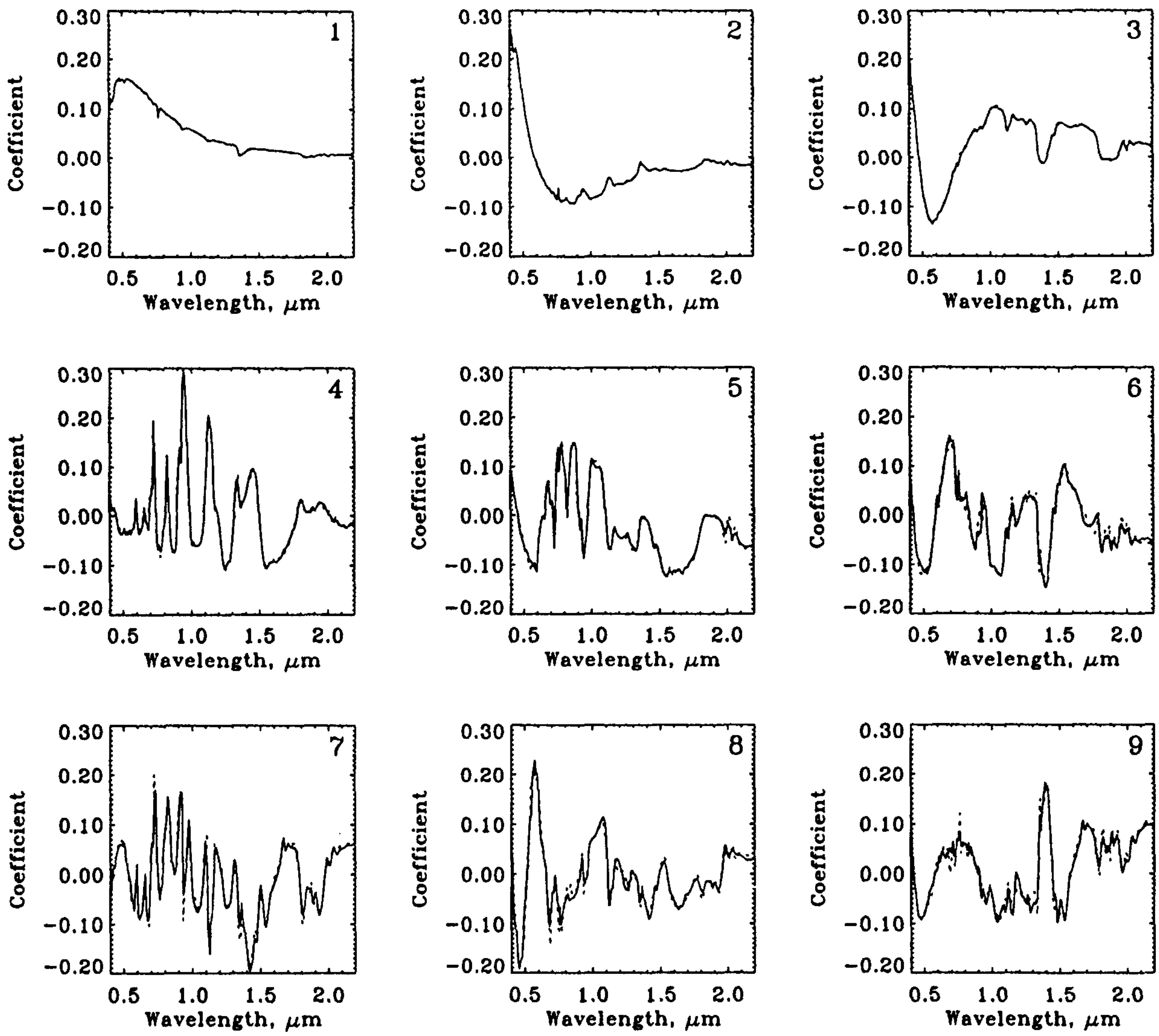

Fig. 7. Nine eigenvectors for the transformed databases. Compare with figure 5.

3.4 Model Search

From above we have shown that irradiance measurements can be compared to MODTRAN models using a statistical transformation. Therefore, spectra in each database can be matched, allowing for rapid searches for MODTRAN parameters that can be used to drive the calculation of the ground-sensor portion of the atmospheric path effects. Using spectra from the Boulder irradiance database, three spectra taken under different conditions were matched with spectra from the MODTRAN database in transform coordinates (fig. 8). The parameters obtained are given in Table 2.

Table 2. Retrieved MODTRAN parameters for 3 irradiance spectra

	Irradiance Spectrum		
MODTRAN parameter	bright	medium	dark
atmosphere	tropical	tropical	mid-latitude summer
water vapor	1.4 cm	1.4 cm	.85 cm
aerosol profile	maritime	desert	urban
cloud profile	sub-visual cirrus	cirrus	stratocumulus
visibility	15 km	100 km	15 km
solar zenith	0	60	0
Actual Conditions			
solar zenith	26.0	48.1	41.3
cloud profile	no clouds	medium cirrus	stratocumulus

The results shown in figure 8 are encouraging in that the values match well in the atmospheric windows. However, the intervals in solar zenith angle and atmospheric water vapor in the MODTRAN database are very coarse and that leads to compensation in other parameters chosen, such as cirrus cover. The MODTRAN modeled transmission in the wings of the water vapor absorption features does not agree with the irradiance measurements and the departures are similar to those seen in model-corrected AVIRIS data.

Analysis of the irradiance and model data sets reveals systematic departures from equivalence that can be ascribed to model inaccuracies in the wings of water vapor features and potential instrument radiometric calibration errors. The systematic errors are very similar to those seen in the gain coefficients derived from the empirical algorithm EFFORT (Boardman, 1998; Goetz et al, 1997).

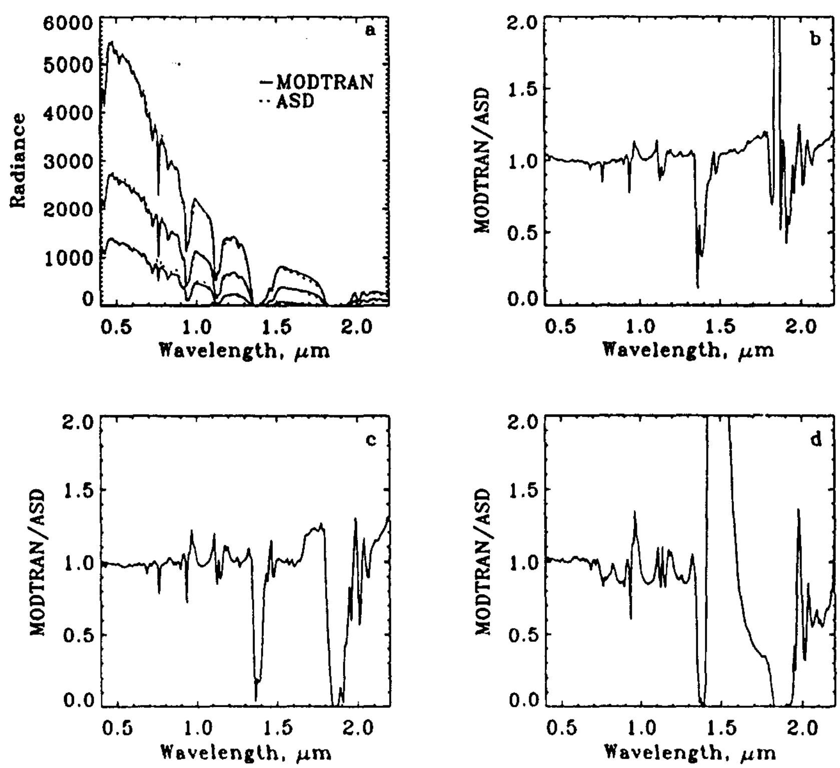

Fig. 8. Results of a search for the best match between 3 irradiance spectra and the MODTRAN database spectra (a). Ratios between the MODTRAN and measured irradiance spectra are shown in b,c,d.

4. Summary and Conclusions

Hyperspectral imaging requires that atmospheric corrections be made in order to be able to exploit the 60% of the 0.4-2.5 μm spectrum influenced by spatially-variable water vapor absorption and other absorbers and scatterers. A number of techniques have been developed to derive apparent surface reflectance from the data themselves. The quality of the results is approximately proportional to the amount of time and effort expended on the correction. Parameterization of the radiative transfer model database makes it possible to develop an ideal lookup table that allows a direct single pixel correction for solar irradiance, aerosol and molecular scattering and gaseous absorption. By utilizing a pixel-by-pixel correction with a rapid algorithm such as ATREM, the residual errors due to differential path length across a scene with topographic relief will be minimized. Furthermore, the processing time will be considerably reduced when compared to first-principles-based, non-linear inversion techniques.

This technique needs further work before it can be applied on a routine basis. Both the measured irradiance and the MODTRAN model databases need to be expanded. The measurement suite of irradiance spectra needs to include conditions of higher water vapor content and greater aerosol loading. These might be obtained from the DOE CART site at which a FieldSpec™FR is being installed to operate continuously. The MODTRAN database needs to be recalculated at a finer resolution in solar zenith angle and water vapor, and surface elevation needs to be added as a parameter.

5. Acknowledgments

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6. References

Anderson, G.P., J. Wang, and J. H. Chentwynd, 1995, MODTRAN3: An Update and Recent Validations Against Airborne High Resolution Interferometer Measurements, *Summaries of the Fifth Annual JPL Airborne Earth Science Workshop*, **1**, 5-8.

Berk, A., L.S. Bernstein and C.C. Robertson, 1989, MODTRAN: A moderate resolution model for LOWTRAN 7, Final Report, GL-TR-0122, AFGL, Hanscom AFB, MA, 42p.

Boardman, J.W., 1998, Post-ATREM Polishing of AVIRIS Apparent Reflectance Using EFFORT: A Lesson in Accuracy Versus Precision, *in This Proceedings.*

Clark R.N., G.A. Swayze, K.B. Heidebrecht, R.O. Green and A.F.H. Goetz, 1995, Calibration to surface reflectance of terrestrial imaging spectrometry data: Comparison of methods, *Summaries of the Fifth annual JPL Airborne Earth Science Workshop*, **1**, 41-42.

Conel, J.E., R.O. Green, G. Vane, C.J. Bruegge, R.E. Alley, and B. Curtiss, 1987, Airborne Imaging Spectrometer-2: Radiometric spectral characteristics and comparison of ways to compensate for the atmosphere, Proc. *SPIE* **834**, 140-157.

Gao, B.-C., K. B. Heidebrecht, and A. F. H. Goetz, 1993, Derivation of Scaled Surface Reflectances from AVIRIS Data, *Remote Sens. Environ.*, **44**, 165-178.

Goetz A. F. H., J. W. Boardman, B. Kindel and K. B. Heidebrecht, 1997, Atmospheric Corrections: On Deriving Surface Reflectance from Hyperspectral Imagers, Proceedings *SPIE*, **3118**, 14-22.

Green, R.O., D.A. Roberts and J.E. Conel, 1996, Characterization and compensation of the atmosphere for the inversion of AVIRIS calibrated radiance to apparent surface reflectance, in *Summaries of the Sixth Annual JPL Airborne Earth Science Workshop*, **1**, 135-146.