USING NIGHTTIME LIGHTS TO VALIDATE THE SPECTRAL CALIBRATION OF IMAGING SPECTROMETERS

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1. INTRODUCTION

This paper proposes a new method for the in-flight validation of spectral calibration based on surface light sources that contain sharp spectral emission lines. The technique is demonstrated using data collected by AVIRIS over Las Vegas, NV at night. This new approach is proposed because the spectral calibration of Earth-looking imaging spectrometers must be known in order to perform quantitative spectroscopy and atmospheric model-based reflectance inversion (Green 1998). However, environmental differences between laboratory and flight, as well as the shock and rough handling associated with launch and flight, contribute to uncertainty in the spectral calibration of imaging spectrometers. While it is possible to directly measure spectral calibration in the laboratory (Chrien et al. 1990), it is difficult to repeat these measurements in the airborne or spaceborne setting. Restrictions in sensor mass, volume, power, and cost, combined with the desire to limit onboard mechanical devices and reduce risk, all work to compromise what can be accomplished using onboard methods. Atmospheric absorption features have been used to pursue validation of the spectral calibration based on a parameterized model of the sensor spectral characteristics (Green et al. 1988, Goetz et al. 1995, Green 1995). The spectral calibration parameters may be deduced by minimizing a least-squares comparison between a high-resolution model spectrum and an imaging-spectrometer-measured spectrum. Disadvantages with this approach arise from the low number of suitable atmospheric spectral absorption features, variability in the absorption features, as well as interference from underlying ground surface reflectance.

2. BACKGROUND

The spectral calibration of an imaging spectrometer describes the way in which the upwelling spectral radiance is sampled and convolved by the spectral response function. Imaging spectrometers operating in the 400- to 2500-nm spectral range typically have 10-nm sampling and 10-nm-wide response functions. This resolution and sampling is sufficient to capture most of the spectral information inherent in the liquid and solid materials found on the Earth's surface. In addition, some form of atmospheric correction is required to invert the measured upwelling spectral radiance to apparent surface reflectance. Inversion methods based on forward models such as the MODTRAN radiative transfer code (Berk et al. 1989) calculate the at-sensor spectral radiance at high spectral resolution. This inversion approach requires accurate knowledge of the spectral calibration. Gaps in the knowledge of spectral calibration cause significant errors in the derived reflectance.

The spectral calibration of an imaging spectrometer is determined in the laboratory by observing the signal response to a scanned narrow-band spectral line output by a monochromator. This approach is repeated for as many spectral and spatial channels as is practical. The measured spectral response functions are often well modeled by Gaussian shaped functions. For this case, the spectral calibration is reported as center wavelength and full width at half maximum (FWHM) for each channel with calculated uncertainties. In the laboratory accuracies of 0.1nm may be achieved. However, the spectral calibration of airborne and spaceborne imaging spectrometers may change when the sensor is in the operational environment.

This uncertainty leads to the general challenge of in-flight and on-orbit spectral calibration for airborne and spaceborne imaging spectrometers. Laboratory calibration is most useful for establishing the general spectral characteristics. One approach to track changes in spectral calibration is by using an onboard spectral calibration source. However, this is generally an expensive option that includes new challenges in tracking the stability of the onboard source. A second approach is to use atmospheric absorption features in order to verify spectral calibration. This paper proposes a new approach that makes use of bright spectral emission lamps located on the surface below the sensor.

3. THEORY

The spectral response function of an imaging spectrometer with Gaussian channel shapes may be expressed as:

$$\mathbf{SRF} = e^{-\alpha\left(\frac{\lambda - \lambda_c - \lambda_{c\_shift}}{\Delta\lambda - \Delta\lambda_{shift}}\right)^2}$$

where the constant α is 4*ln(2), λ is the wavelength, λ_c is a vector of center wavelengths for each detector element and $\Delta\lambda$ is a matching vector of FWHM channel widths, as measured during laboratory calibration. Two additional vectors may be used to express the change in center wavelength , λ_{c_shift}, and change in channel width, $\Delta\lambda_{shift}$, to account for any changes in the spectral response function since the laboratory calibration. For imaging spectrometers, it is reasonable to assume that if a shift occurs in one spectrometer channel, then it is likely that a correlated shift occurred in adjacent channels. This assumption suggests that for some limited number of contiguous spectral and spatial elements, the shift in center wavelength or channel width can be assumed to be a constant. This result is useful since if the spectral calibration shift can be detected if a few channels across the spectrum, the impact may be predicted for all remaining spectral channels.

4. CURRENT METHODS

Available methods for detecting change in the spectral calibration include use of an onboard spectral calibrator and use of atmospheric absorption features. While it is possible to build a highly accurate and effective onboard spectral calibrator, there are cost, packaging, and other technical limitations that discourage this choice. Ideally, the spectral calibrator would make use of the same scanning monochromator method used during ground calibration. Other methods include inserting a spectrally detailed signal such as a laser, a spectral line lamp, or a a tungsten lamp through a transmittance or reflectance filter. The basic challenge with all these methods is inserting the signal into the optical system in exactly the same way that light from the ground passes through the optical system. A simple measurement shows that the spectral response function shape and position is substantially different when the full aperture path of the optical system is not used as shown in Figure 1.

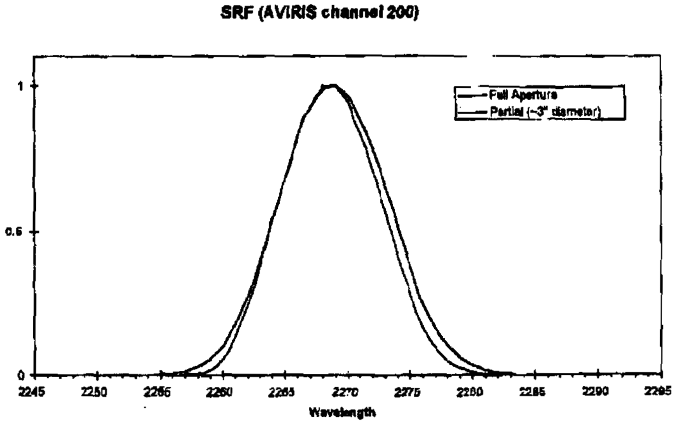

Figure 1. Difference in spectral response function between fully and partially filled aperture measurement.

Using atmospheric absorption features to assess the shift in spectral calibration has the advantage of making use of the full optical aperture and throughput of the system. A number of lines are available, including oxygen, water vapor, and carbon dioxide. To make use of these features, a good quality radiative transfer model such as MODTRAN is required. An example of the inputs to this approach are given in Figure 2. The MODTRAN-modeled spectrum may be passed through the AVIRIS laboratory spectral response functions and the residual can be calculated in the vicinity of the atmospheric absorptions. The spectral response functions may then be shifted and the residual may be calculated until the residual is minimized. The result is an estimation of the in-flight or on-orbit spectral calibration in the vicinity of the atmospheric absorption. For this method, knowledge of the surface reflectance and atmospheric water vapor is required. Also, there are only a limited number of usable absorption features in the solar-reflected spectrum, and these features are not necessarily located in optimal portions of the spectrum.

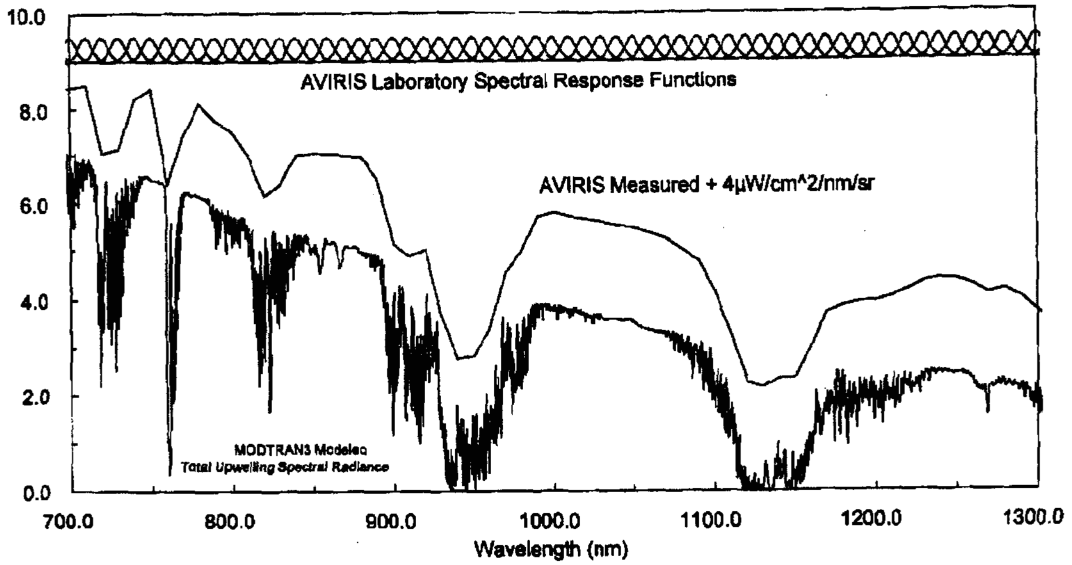

Figure 2. MODTRAN-modeled spectrum with AVIRIS-measured spectrum and laboratory spectral response functions.

5. PROPOSED METHOD

A new method for in-flight and on-orbit spectral calibration that uses ground-based spectral lights is proposed here. To explore this method a nighttime AVIRIS data set was acquired over the city of Las Vegas, NV. Bright lamps with sharp spectral emission lines are commonly used for nighttime lighting of buildings. Figure 3 shows the nighttime image of Las Vegas acquired by AVIRIS. Figure 4 show a ground-based picture of the lights illuminating the buildings. Las Vegas offers a large number of spectral emission line wavelengths. One of the more interesting lines was associated with the illumination of the MGM Grand Hotel, which is illuminated by hundreds of 1000-W metal halide lamps. These lamps are essentially mercury vapor lamps doped with metal halide compounds to produce bright, narrow lines of different colors in the visible portion of the spectrum. At the hotel, the metal halide lamps emit a large fraction of their radiant energy in a very narrow band near 535 nm. This produces the nighttime green color of the hotel. A spectrum from AVIRIS of the MGM Grand Hotel is given in Figure 5.

These emission lines provide a spectral source that may be used to deduce the in-flight or on-orbit spectral calibration of imaging spectrometers. For this new method, a lamp emission line spectrum of high spectral resolution is convolved with the imaging spectrometer baseline spectral calibration and a residual is calculated between this modeled spectrum and the spectrum measured by the sensor. The residual is then recalculated for shifts in the baseline calibration parameters until a suitable minimum is reached. The spectral calibration characteristics are then updated in the lamp emission line wavelength region for the determined shift values.

Figure 4. Picture of Las Vegas from the ground.

6. PRELIMINARY ANAYSIS AND RESULTS

This method was applied to the AVIRIS data set acquired over Las Vegas based on the 535-nm emission line of the lamps illuminating the MGM Grand Hotel. At the time of this preliminary analysis a high-spectral-resolution spectrum of the metal halide lamp was not available. Therefore, to begin exploration of this analysis method, the high-resolution spectrum was simulated as two narrow spikes. In Figure 6 the simulated lamp emission spectrum and the AVIRIS measured spectrum are shown. The preliminary result after calculating the residuals for a range of spectral shifts, was a shift of 2.4 nm. This result is known to be uncertain because simple spikes were used to simulate the spectrum of the MGM Grand Hotel metal thalide lamps. Nevertheless, this preliminary analysis demonstrates the approach of this new in-flight or on-orbit spectral calibration method

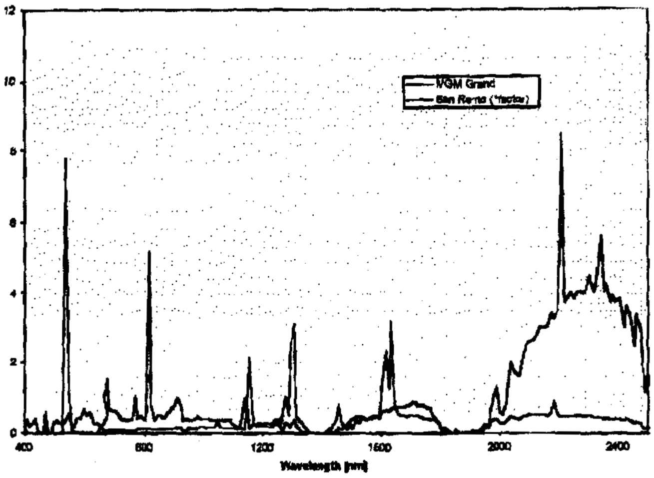

Figure 5. AVIRIS spectra from Las Vegas image.

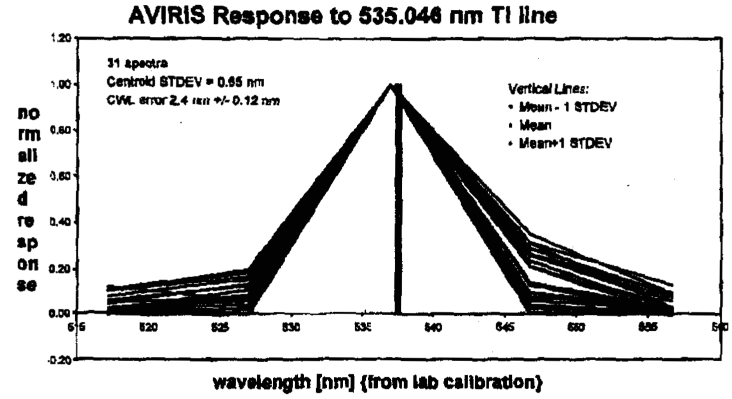

Figure 6. Simple model results of spectral validation for AVIRIS. The vertical lines are the simulated emission. The other curves are the AVIRIS measurements. Results indicate a need to more accurately model the emission line.

7. DISCUSSION

This new method for in-flight or on-orbit spectral calibration offers a number of advantages. There are many lamps with different emission lines from which to select. With laboratory measurements the high-spectral-resolution spectra of lamp emission lines may be accurately measured. Lamps with different emission lines may be selected to cover all portions of the 400- to 2500-nm spectral region. At comparatively low cost, lamps may be set up specifically to validate the operational spectral calibration of spaceborne sensors. Table 1 gives a list of several airborne and spaceborne imaging spectrometers for which we could use this approach to determine in-flight or on-orbit spectral calibration.

Table 1. Imaging Spectrometer Systems

Sensor/Platform	Ground Resolution (meters)	Spectral Resolution (nanometers)	Radiometric Resolution @ 535 nm [μW/cm^2 sr nm]
AVIRIS/ER-2	20	10	0.012
AVIRIS/Twin Otter	2-4	10	0.012
HYDICE/CV580	1-5	5-20 (7.8)	0.012
OV-4/WF-1	8	11	0.020*
Hyperion/EO-1	30	10	0.050
COIS/NEMO	30	10	**

*Model estimate

**Data not available

8. CONCLUSION

A new method for determining the in-flight or on-orbit spectral calibration of imaging spectrometers has been proposed. This method uses ground-based lamps with strong spectral emission line to provide sources for spectral calibration while the imaging spectrometer is in operation. This method has been preliminarily applied to an AVIRIS data set acquired over Las Vegas, NV. The results of the Las Vegas data set support the validity of the approach. Additional refinement is needed in the knowledge of the underlying high spectral resolution spectrum of the emission line lamps. The method has cost, implementation, and flexibility advantages over onboard spectral calibrators. The method offers spectral calibration feedback through more of the spectrum with more stability than the atmospheric based validation of spectral calibration. This is an important new method to improve operational spectral calibration of airborne and spaceborne imaging spectrometers.

9. REFERENCES

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10. ACKNOWLEDGEMENTS

The majority of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. We would like to express our appreciation for the efforts of the AVIRIS team at the Jet Propulsion Laboratory.