On-Orbit Spectral Calibration Verification of Hyperion

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***Abstract* – On November 21, 2000, NASA launched the EO-1 satellite, carrying the Hyperion hyperspectral imager, into an orbit precisely following LANDSAT-7 by 1 minute. Hyperion has a 7.5 km swath width, a 30 meter ground resolution and 220 spectral bands. Its spectral bands extend from 400 nm to 2500 nm with each band having about a 10 nm bandwidth. A unique process to validate the spectral calibration that is based on an the atmospheric limb data collect has been developed. The data contained a collection of solar lines, atmospheric lines and absorption lines from the paint which coats the solar calibration reflectance panel. Correlating the positions of these lines with reference data, the center wavelength of each pixel across the field of view for the SWIR spectral regions of the imaging spectrometer has been verified. In this paper we discuss the data collection and the technique applied to the SWIR focal plane array.**

I. Introduction

One of the primary missions for the Hyperion program is to characterize the radiometric performance of the imaging spectrometer on-orbit and compare it against the performance established during ground acceptance tests. One of the key performance parameters is the spectral calibration, i.e. the center wavelength of each spectral pixel for each row of pixels along the spatial dimension.

The observational data required to perform this verification must contain clearly defined spectral features that can be identified and traced to a reference spectrum. We attempted to use features in ground scenes but difficulties arose in removing the spectral continuum. The variable spectral reflection of the earth's surface added substantial uncertainty to the process.

Fortunately, a data collection of earth's atmospheric limb provided us with a more tractable data source. The atmospheric limb is essentially a solar calibration scheduled such that the instrument views the sun through different tangent heights of the atmosphere. In order to view the sun, the spacecraft performs a yaw maneuver such that sunlight reflects off the solar calibration panel into the instrument aperture. The result is a collect that is uniform across the field of view and contains spectral features, which can be matched with solar lines, atmospheric lines and absorption lines associated with the paint on the instrument cover.

We developed a process to identify and match the known spectral features with those in the Hyperion spectrum and then derive the corresponding center wavelengths for each pixel on the focal plane. This paper discusses the details of the data collection event, the atmospheric limb's spectrum and the process of performing the spectral calibration. The results for the derivation of the spectral calibration for the SWIR focal plane on-orbit is presented along with comparison with the calibration made during ground acceptance tests described previously by Liao [1].

II. Discussion Of Data Collection

A. Atmospheric Limb Collect

The Hyperion instrument telescope cover has three normal positions: closed, open and the solar calibration position. When Hyperion views the ground or the moon, the cover is in the open position. When Hyperion views the sun, the cover is in the solar calibration position—which is 37 degrees from the closed position—and the spacecraft must perform a yaw maneuver so that the instrument views the reflection of the sun off the inside of the cover. A diffuse white paint containing distinct spectral lines coats this surface. The atmospheric limb collect is essentially the same as a solar calibration but timed so that the sun is rising through the limb of the earth and the sun's rays pass through the atmosphere before reaching the instrument, (Fig. 1). The orbital motion of EO-1 allows Hyperion to sample different cross-sections of the atmosphere during image acquisition, which typically lasts 12 seconds. Fig. 2 is an example of the data that the instrument collects during one atmospheric limb collect.

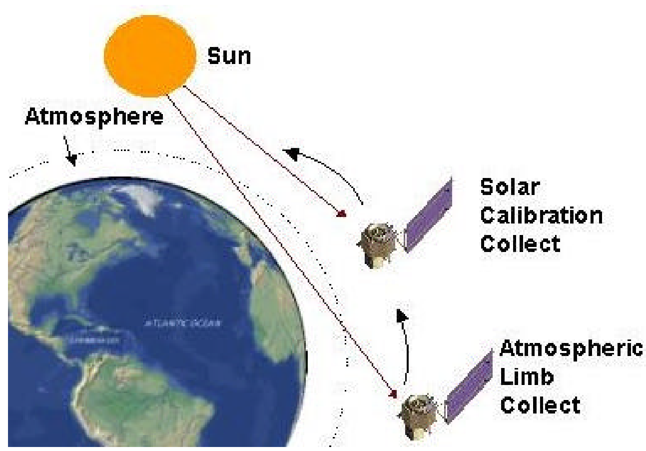

Fig. 1: Schematic of Atmospheric Limb Collect

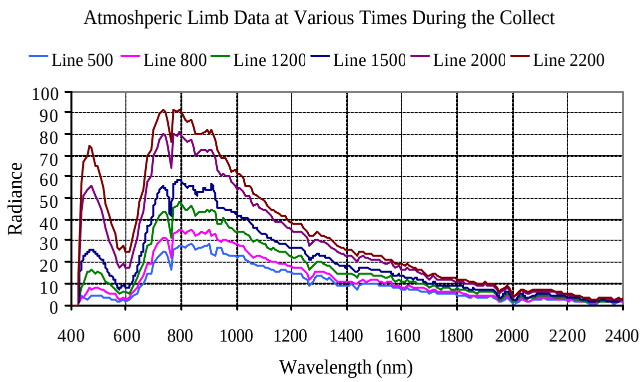

Fig. 2 Hyperion spectral profiles corresponding to five different grazing distances obtained during an atmospheric limb collect

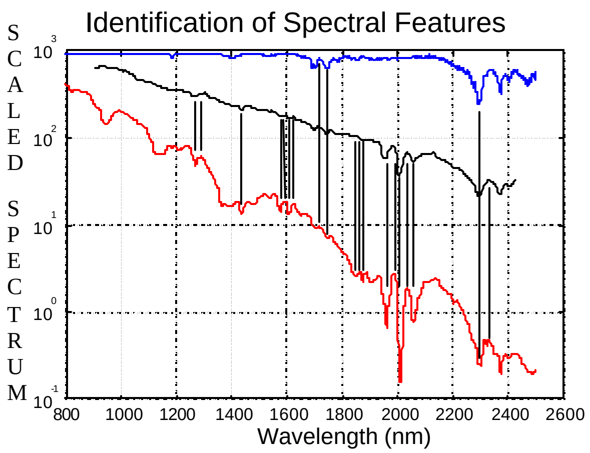

Fig. 3 Sample Hyperion Spectrum in the SWIR (black) compared with an atmospheric model (red) and the measured reflectance of the cover paint (blue).

B. Reference Spectrum

In order to perform the spectral validation, the collected limb spectrum must not only have distinguishable features but also be referenced to a known spectrum. Fig. 3 compares the Hyperion spectra with the measured reflectance of the cover paint and the atmospheric lines. Correlation points between the Hyperion spectra and features in the cover paint or atmospheric spectra are indicated. The spectrum for the cover paint was obtained by making diffuse reflectance measurements of paint samples with a Cary 5 spectrometer and BioRad Fourier transform spectrometer at TRW. The atmospheric lines in the SWIR were obtained from PLEXUS—a general user interface built for MODTRAN-3, ver. 1.5.

II. Data Analysis

We applied the following steps for the SWIR spectral verification. We refer to the two axes of the focal plane as 1) the spectral *band*, and 2) the spatial field of view (*FOV*).

1.) *Create Pseudo-Hyperion Spectra from the Reference Data*: The calculated atmospheric limb profile was adjusted to include cover reflectance effects: paint reflectance, BDRF (bi-directional reflection factor), and the spectral angle of reflection. The high-resolution spectrum, sampled at 0.5 nm intervals, was convolved with the instrument's spectral broadening coefficient. This operation was performed on a pixel-by-pixel basis because the broadening coefficient varied slightly across the focal plane. Finally, the spectrum was fit with a cubic spline to more accurately determine the wavelength positions of peaks and troughs.

2) Correlate Spectral Features: First, we made a visual comparison between the Hyperion and reference spectra in order to identify features of significant strength and spatial presence to be included in the calculations. Nineteen features were identified in the Hyperion atmospheric limb spectrum. For each spectral feature—in a given FOV—the location of the peak or trough, in band number units, was determined by applying a cubic spline and calculating the extremum. This was matched with the wavelength of the corresponding feature in the reference spectrum. We repeated this process for each FOV location to take into account the spectral smile. Calculating peak locations using spline interpolation introduced a ±1.1 nm error distribution (determined using empirical sampling of the high-resolution reference spectrum).

3) *Calculate Band-to-Wavelength Map:* The correlation process in step 2 resulted in a 2D surface: the Hyperion band position of a spectral feature (x), the field of view position (y), and the corresponding wavelength of the feature obtained from the reference spectrum (z). We applied a low order polynomial fit to statistically reduce noise in the data and produce a band-to-wavelength map for the focal plane.

III. Results

A. Direct Comparison with Pre-Orbit Measurements

Pre-orbit measurements were made at select wavelengths. There were four spectral features in the atmospheric limb reference spectra that were close in wavelength to these ground measurements. These wavelengths and those corresponding to the spectral band number are compared in Table-1. The most significant difference occurs in a region where there are multiple lines in the atmosphere. We have reservations about the wavelength accuracy of the calculated features in the vicinity 2000 ± 15 nm (having found another suspected error in the VNIR regime, perhaps related to inaccurate model parameters). The results based on the cover lines are in much better agreement with the ground calibration. The accuracy of the technique is limited to the accuracy of the reference spectra. The next largest source of error is due to the use of the spline in determining the peak and trough positions (±1.1 nm). Overall, this comparison indicates that the on-orbit measurements support the ground calibration to within half a pixel. Each pixel has about a 10 nm bandwidth.

TABLE I
COMPARISON OF ON-ORBIT AND GROUND RESULTS

Spectral Pixel No.	TRW [nm]	On-Orbit [nm]	Delta [nm]	Reference
17	1013.00	--	--	--
47	1315.12	1315.4	+0.28	Atm.
86	1711.55	1710.5	-1.05	Cover
116	2012.19	2015.5	+3.31	Atm.
146	2313.97	2315.4	+1.43	Cover

B. Comparison with Ground Full Spectral Calibration

The pre-orbital calibration was extended to the entire focal plane by applying a polynomial fit to the data. The resulting full calibration consisted of a center wavelength value for each pixel. We applied the same process to our results. The following two figures compare the results from the ground spectral measurements to the ground based spectral calibration and the on-orbit calibration. Note that for Band 17, Fig. 4, the center wavelength as well as the variation of the center wavelength across the field of view is in excellent agreement with the ground calibration. For Band 146, Fig. 5, the on-orbit spectral calibration has about a 1.5 nm offset, and the center wavelength variation across the field of view has the same trend as the ground spectral calibration.

Fig. 6 presents the difference between the on-orbit and the ground calibrations. The largest difference is in the 2000 nm regime, which is dominated by uncertainties in the reference atmospheric profile.

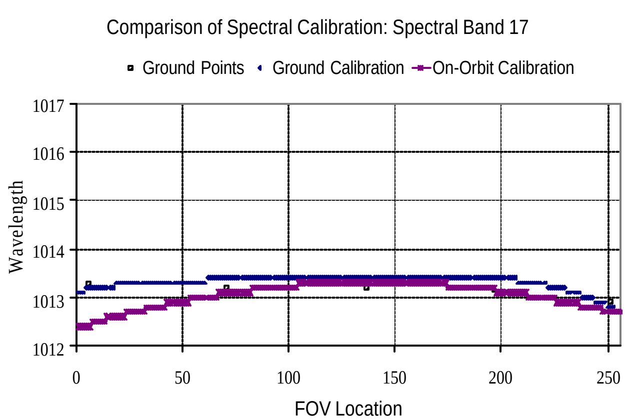

Fig. 4 Comparison of Spectral Calibrations for Band 17

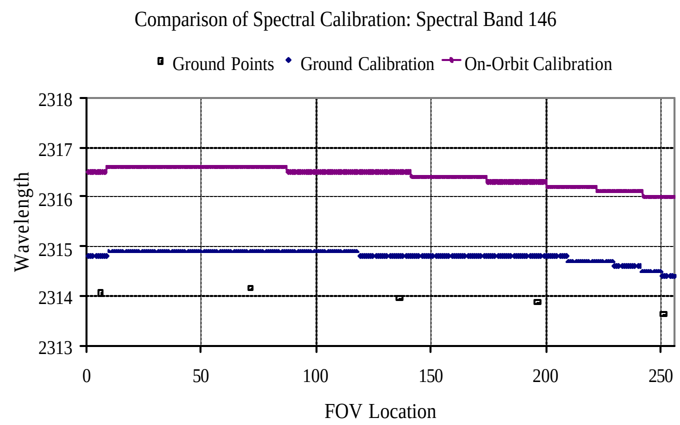

Fig. 5. Comparison of Spectral Calibrations for Band 146

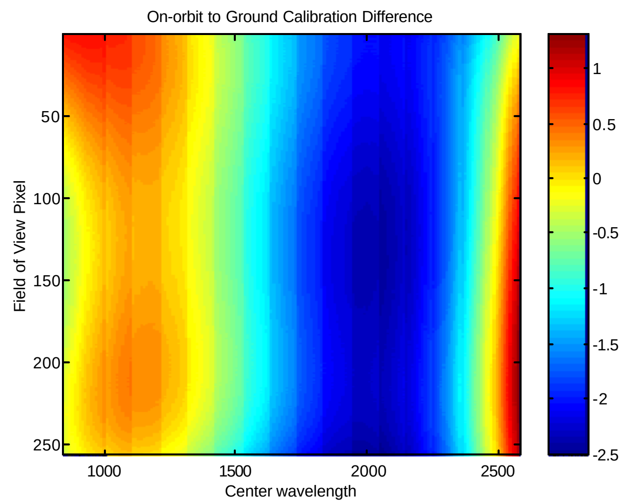

Fig. 6 Difference Between On-Orbit and Ground Calibration

IV. CONCLUSIONS

We developed a data collection and analysis process to validate the spectral calibration of Hyperion from space. The process was based on an atmospheric limb data collect in which the rays of the sun passing through the atmosphere and reflecting off the Hyperion cover is used. The results confirm that the Hyperion ground spectral calibration is valid for on-orbit operations. The largest sources of uncertainty in the process are suspected errors in the calculated atmospheric profile.

REFERENCES

[1] L. Liao, P. Jarecke, D. Gleichauf and T.Hedman, “Performance Characterization of the Hyperion Imaging Spectrometer Instrument”, *Proc. of SPIE*, Vol. 4135, pp. 254-263, August 2000.