

Quantitative Effects of the Spectral Calibration Accuracy of the Imaging Spectrometer on the Vegetation Red Edge

Y Q Zhang^{1,2}, Z C Chen^{*1}, W J Zhang¹ and H Zhang¹

¹Institute of Remote Sensing and Digital Earth Chinese Academy of Sciences, 100094, Beijing, China.

²University of Chinese Academy of Sciences, 100049, Beijing, China.

E-mail: zcchen@ceode.ac.cn

Abstract. The red edge position (REP) has been widely used to estimate vegetation parameters and also as a sensitive indicator of vegetation stress. Detailed characterizations of REP can be easily achieved from hyperspectral data obtained from imaging spectrometers. After launch of imaging spectrometers, shift in the center wavelength of the spectral channel may occur due to the vibrations and aging of components. In this paper, we firstly proposed a method to quantify the effects of the spectral shift of imaging spectrometers on the REP. The fundamental basis of the method was the simulation of the vegetation reflectance spectra after spectral shift (SSR). The quantitative relationship between the spectral shift value and the REP derived from the SSR was analysed. The result showed a significant linear relationship between spectral shift value and REP error ($R^2=0.9932$). For a 10nm resolution spectrometer, channel center wavelength errors of 10%, 30% and 50% would introduce 0.8nm, 2.5nm and 5.3nm error in REP, respectively. The study indicated that spectral calibration error was an important factor to generate REP shift.

1. Introduction

Imaging spectrometers are being increasingly used in the remote sensing of the earth system processes. The large amount of narrow observation channels makes imaging spectrometers a useful tool for information extraction from discrete absorption features of both atmosphere and surface constituents. The depth, shape, and spectral location of these features are key variables in the characterization of the corresponding natural species. The point of maximum slope on the reflectance spectrum of vegetation between 680 and 750nm, termed as the red edge position (REP), has been widely used to estimate vegetation parameters and also as a sensitive indicator of vegetation stress. The REP marks the boundary between chlorophyll absorption in the red wavelengths and the high infrared reflectance due to leaf internal scattering. Detailed characterizations of REP can be easily obtained from hyperspectral data of imaging spectrometers.

The imaging spectrometer performance might change after launch into space or after installation in an aircraft, because of processes such as outgassing, aging of optical or electronic components, and misalignment due to mechanical vibrations [1]. In particular, spectral shifts are very likely to appear in detector arrays mounted in the focal plane of imaging sensors. Previous studies confirmed that errors in the derived reflectance spectrum appear due to this shift [2], especially in the spectral region with



sharp rise or fall of the reflectance, such as the red edge region. There is still no study about the effects of the spectral shift of imaging spectrometers on the REP. In this paper, we proposed a method to analyze this problem. Firstly, the vegetation reflectance spectra with different spectral shift (SSR) were simulated, and then the quantitative relationship between the spectral shift value and the REP derived from the SSR was analyzed.

2. Method

To assess the effects of the spectral shift of imaging spectrometers on the vegetation REP, some representative vegetation reflectance spectrum with several spectral shift value of imaging spectrometer were calculated. The MODTRAN4 radiative transfer code was used to model high-resolution top-of-the-atmosphere (TOA) vegetation radiance spectrum at the top of the atmosphere and atmospheric correction parameters. The simulation process is outlined in figure 1.

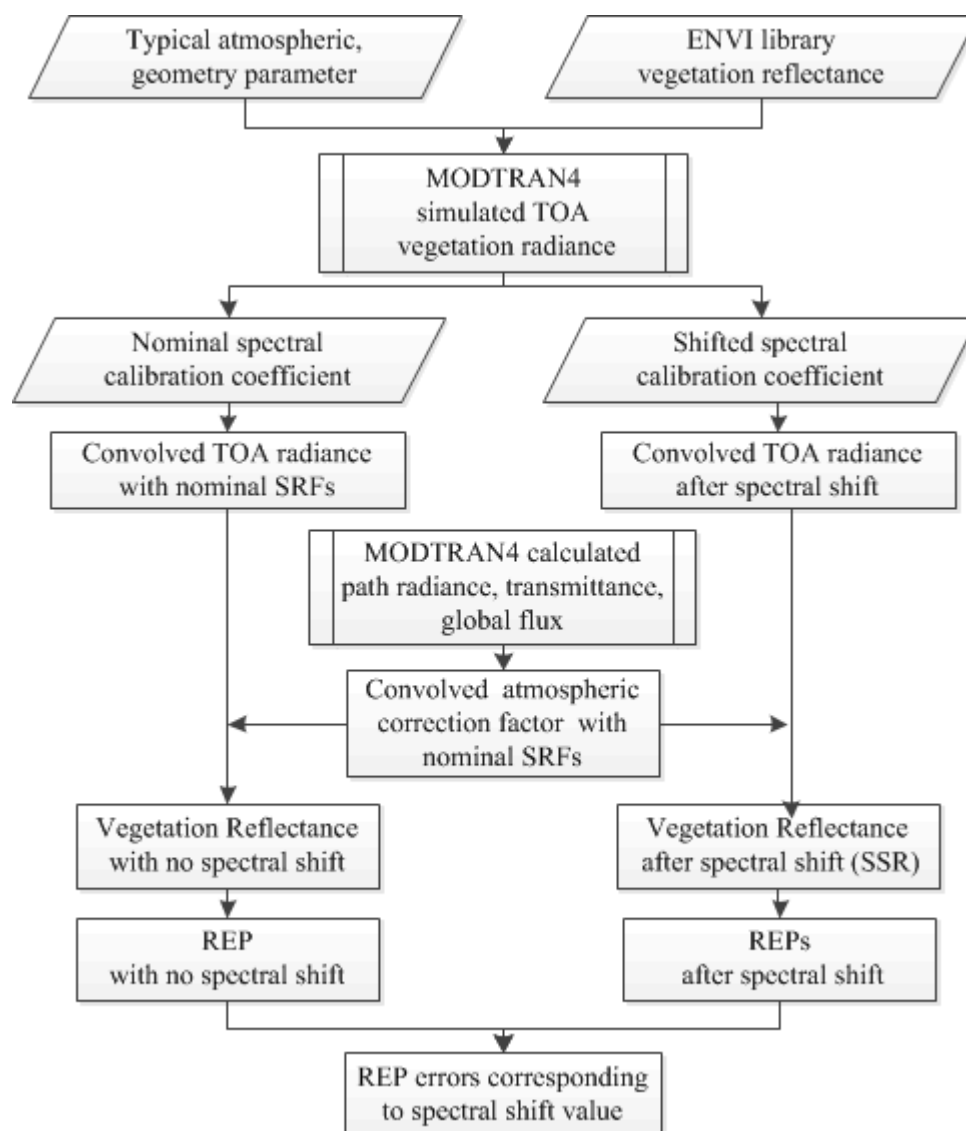


Figure 1. Data simulation process.

2.1. High-resolution vegetation TOA radiance simulation

The MODTRAN4 radiative transfer code was used to simulate the high-resolution vegetation TOA radiance with 0.1-nm spectral resolution by vegetation surface reflectance. Seven typical vegetation reflectance spectra were selected from the ENVI veg_2grn.sli library. Typical atmospheric and geometry parameters in table 1 were used in MODTRAN4 calculation procedure.

Table1. Modtran4 input parameters in the simulation of TOA radiance.

Modtran4 parameters	Value	Description
MODEL	2	Mid-Latitude Summer
ITYPE	2	Vertical or slant path between two altitudes.
IEMSC	2	Solar radiance mode
IMULT	-1	Multiple scattering.
LSUN	T	To read 1 cm ⁻¹ binned solar irradiance
CO ₂	390	CO ₂ mixing ratio in 2011(ppmv)
IHAZE	2	RURAL extinction,
GNDALT	0.1	Altitude of surface relative to sea level (km)
H1	1000	Initial altitude (km)
H2	0.1	Final altitude (km)
ANGLE	0	Initial zenith angle as measured from H1
PARM1	90	Relative solar azimuth (degrees) at H2
PARM2	45	Solar zenith (degrees) at H2
DV	1cm ⁻¹	Frequency increment used for spectral outputs

2.2. Simulation of vegetation TOA radiance with different spectral shift value

Several spectral shift values (from -5 to +5 nm in a step of 0.5 nm) for a 10nm resolution spectrometer were selected. A total of 20 TOA radiance for each vegetation reflectance spectrum were simulated by the convolution of the high-resolution MODTRAN4 calculated radiance with spectral response functions (SRFs) in equation(1), whose center wavelengths were shifted with several values from the nominal channel center wavelengths of spectrometer. SRFs were generated with Gaussian function shape. SRF with Gaussian function form is typical for imaging spectrometers that have multiple-aperture response functions convolved with a spectral dispersion function for each spectral channel [1]. To represent the typical imaging spectrometer spectral characteristics, we selected Hyperion band configuration as example.

$$SRF(\lambda_i) = \exp \left[- \left(\frac{\lambda - (\lambda_c(i) + \Delta\lambda)}{fwhm(i)/2\sqrt{\ln(2)}} \right)^2 \right] \quad (1)$$

2.3. Calculation of vegetation reflectance with different spectral shift value

In order to obtain spectral shifted reflectance (SSR) from the simulated radiance, atmospheric correction factor needs to be calculated. First, the atmospheric quantities (path radiance, global flux, and transmittance) were calculated with MODTRAN4 in the original SRFs. The input atmospheric and observation geometry parameters were the same as the TOA radiance simulation, thus only the spectral shift error were introduced to the vegetation reflectance spectrum. Then, SSRs were generated by equation (2).

$$\rho(\lambda) = \frac{[L(\lambda) - L_0(\lambda)]\pi}{E_g(\lambda)[\tau_{dir}(\lambda) + \tau_{dif}(\lambda)]} \quad (2)$$

The usual Lambertian assumption was made to formulate the surface reflectance ρ , where L is the TOA radiance, L_0 is the path radiance, E_g is the global flux (i.e., direct plus diffuse) on the ground, and τ_{dir} and τ_{dif} are the direct and diffuse transmittances (ground to sensor), respectively.

2.4. Derivation of REP corresponds to different spectral shift value

The REP corresponds to different spectral shift was extracted by spectral shifted vegetation reflectance, which based on the inverted Gaussian fitting technique [3] according to equation (3). The quantitative relationship between the spectral shift value and the REP derived from the SSR was analyzed.

$$R(\lambda) = R_s - (R_s - R_0) \exp\left(-\frac{(\lambda_0 - \lambda)^2}{2\sigma^2}\right) \quad (3)$$

$$\lambda_p = \lambda_0 + \sigma$$

Where R_s is the maximum or “shoulder” spectral reflectance, R_0 and λ_0 are the minimum spectral reflectance and corresponding wavelength, and σ is the Gaussian function variance, λ_p is the REP.

3. Result

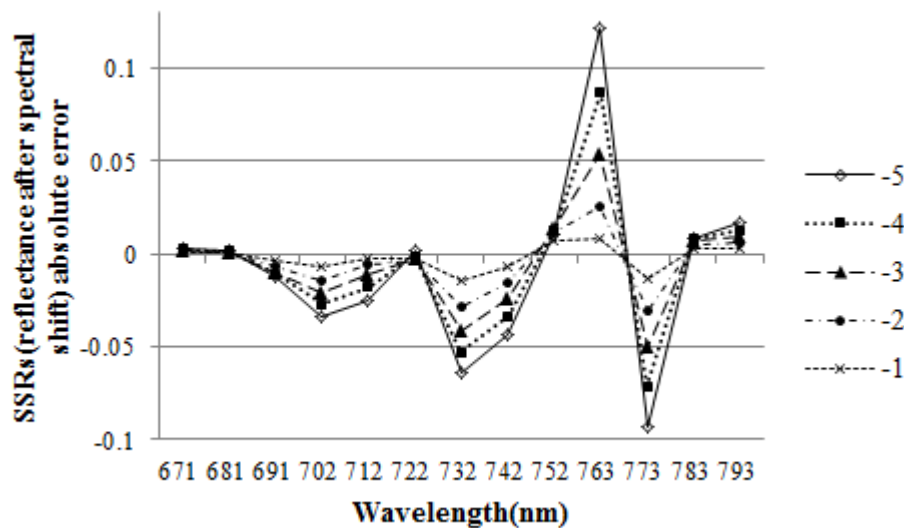


Figure 2. Absolute Error in red edge region of simulated Tarweed reflectance spectra caused by different values of the spectral shift.

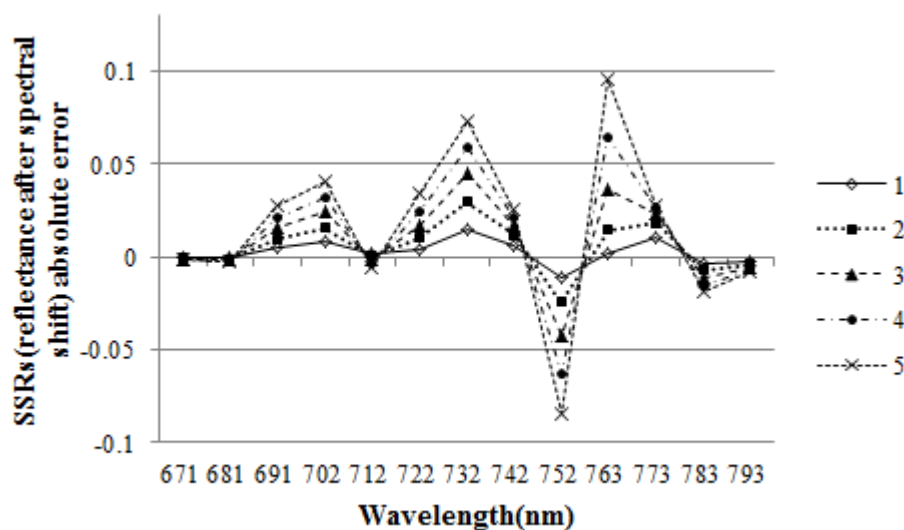


Figure 3. Absolute Error in red edge region of simulated Tarweed reflectance spectra caused by different values of the spectral shift.

For seven typical vegetation types, the error spikes all appeared in the red edge region of the simulated TOA radiance and SSRs with different spectral shift. The absolute error in simulated vegetation reflectance (e.g. Tarweed) caused by the spectral shifts (-5nm+5nm) of Hyperion channels is displayed in figure 2 and figure 3, and the errors larger than 12% was observed in the oxygen bands. In red edge region, the absolute was larger than 7%. Because the input atmospheric and observation geometry parameters in the vegetation TOA radiance simulation were the same as atmosphere correction, the error spikes in the red edge region of the SSRs are caused by the systematic spectral shift.

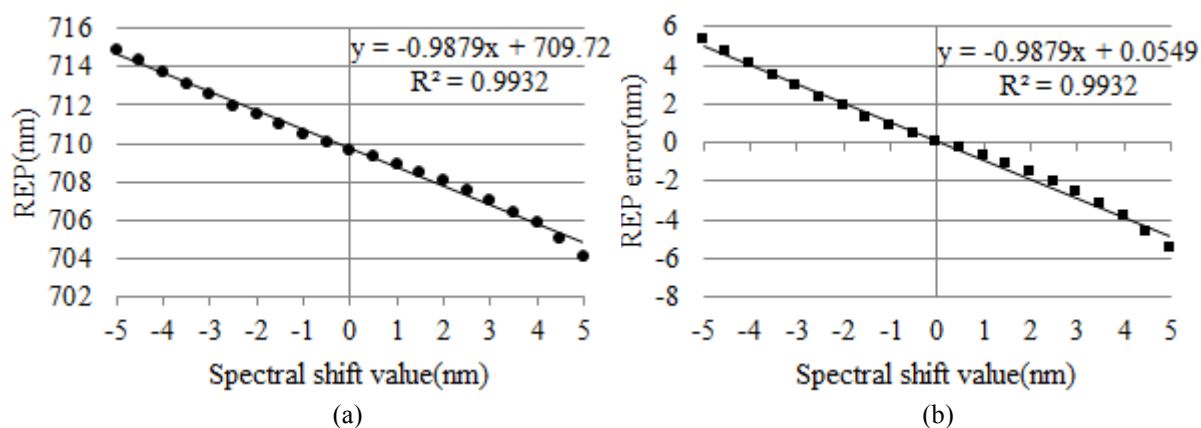


Figure 4. The averaged REPs (a) and REP errors (b) caused by the different spectral shift of seven vegetation types.

The results corresponding to different vegetation are basically consistent. The averaged of REPs and REP errors caused by the different spectral shift of seven vegetation types are showed in figure 4. The result showed that there was a significant linear relationship between spectral shift values and REP errors ($R^2=0.9932$). For a 10nm resolution spectrometer, channel center wavelength errors of 10%, 30% and 50% (1nm, 3nm, 5nm) introduced 0.8nm, 2.5nm and 5.3nm error in REP, respectively.

4. Conclusion and Discussion

The study indicated that channel center wavelength error was an important factor to generate REP shift. REP values are relatively insensitive to vegetation components. Shift of the REP resulting from variation in leaf chlorophyll content or leaf area index is utilized for monitoring vegetation stress. But in the extreme case, REP shift caused by the spectral calibration error may be more significant than which by vegetation biochemical content changes. Therefore, high-accuracy spectral calibration of imaging spectrometers is essential in the vegetation quantitative application related with REP.

References

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