A Simple Method of UV Stray Light Correction for Field Spectrometers in Ground Validation Sites

Ling Li[1*], Zhifeng Wu[1], Caihong Dai[1], Yanfei Wang[1] and Emma Woolliams[2]

[1]*Division of Optics, National Institute of Metrology, China, Beijing, China*

[2]*National Physical Laboratory, Queens Road, Teddington, Middx, TW11 0LW, UK*

Corresponding e-mail address: liling@nim.ac.cn

Field spectrometers are widely applied in ground validation sites for remote sensing and earth observation. However, the stray light is one of the most important factors on accurate measurements, since the spectral distribution of target source differs significantly from the incandescent calibration source. Here, a simple UV stray light correction method for continuously distributed wide-spectrum light sources was established by using bandpass filters. The UV stray lights of field spectrometers in situ measurement was reduced obviously.

INTRODUTION

With the goal of climate change prediction and disaster weather prevention, high accurate spectral radiometric calibration is essential for remote sensing and earth observation [1]. Ground vicarious calibration is one of the most feasible ways to realize SI-traceable radiometric calibration for on-orbit satellites. However, the spectral distribution of solar radiance is different from calibration light source (incandescent lamp). The stray light is a main uncertainty source of laboratory calibrated spectrometers which are transferred to the ground-based validation sites, since CCD spectrometers have problems such as internal structural defects and unsatisfactory optical components, which seriously affect the accurate radiance measurements. Several approaches have been proposed to correct the stray light in CCD spectrometers [2-5]. Zong et al. [3] proposed an efficient and accurate correction method that obtained the spectral line spread functions for every pixel by using a set of monochromatic laser sources. But the tunable lasers are relatively expensive and hard to maintain for most laboratories.

In this paper, the stray light properties of various typical field spectrometers were characterized. A simple, economic correction method was established for continuously distributed wide-spectrum light sources by using bandpass filters. The mathematical correction model was also proposed.

EXPRIMENTS

The stray light properties of four various typical field spectrometers were characterized by using a cut-off filter, which blocks the wavelengths shorter than 450 nm. These spectrometers, FieldSpec4 (ASD), HR-1024i (SVC), PSR+3500 (Spectral Evolution), and CR280 (Colorimetry Research), were calibrated by reflectance plaque and standard lamp. Then the 450 nm cut-off filter was placed in front of each spectrometer, with the same measurement settings, including position, integration time, and the average number of time.

The stray light ratios (σ) in UV wavelengths were calculated by dividing the radiance results with cut-off filter by calibration ones, the formula is $\sigma = L_x/L_c*100$. As is shown in Fig.1, The stray light radios are more than 5% in the wavelength around 350 nm, and σ value of the more compact spectrometer is much higher, such as CR 280.

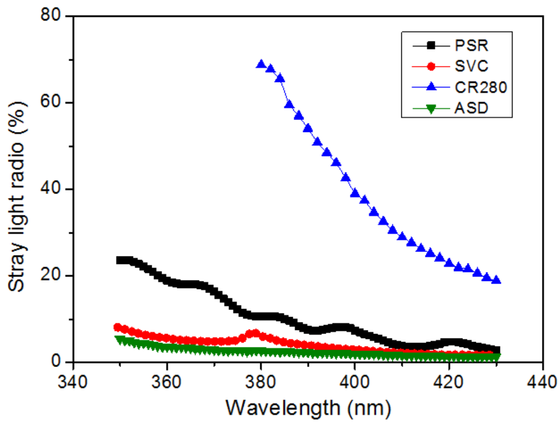

Figure 1. The stray light radios of four field spectrometers.

As is shown in Fig.2, the UV stray light radios owing to different wavelength ranges of CR 280 spectrometer were measured by a set of bandpass filters. The stray light at 380 nm originating from 550nm to infrared wavelengths could be defined as $Y_{\text{stray a},380}$. The stray light at 380 nm originating from 650nm to infrared range could be defined as $Y_{\text{stray b},380}$. Then stray light portion at 380 nm owing to the wavelength range from 550nm to 650nm could be obtained by subtracting $Y_{\text{stray b},380}$ from $Y_{\text{stray a},380}$. Thus, the stray light radio of UV wavelength could be calculated by dividing ($Y_{\text{stray a},380}$-$Y_{\text{stray b},380}$) by integral radiance between 550 nm and 650 nm.

$$R_{stray\ 380,550nm\text{-}650nm}=\frac{Y_{stray\ a,380}-Y_{stray\ b,380}}{Y_{meas,\ 550nm\text{-}650nm}}$$

Similarly, the UV stray light radios owing to 650 nm to 800 nm, and 800 nm to near infrared ranges could be obtained, respectively.

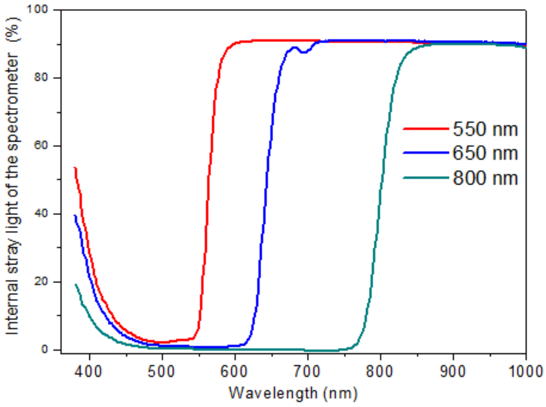

Figure 2. Stray light radios of CR280 by different bandpass filters.

CORRECTION METHOD

The total signal from spectral stray light at a given wavelength (λ_i) is the sum of all spectral stray light contributions from the broadband source spectra falling on the elements. For continuously distributed wide-spectrum light sources, the stray light effect of longer wavelengths on UV adjacent wavelengths is similar. Therefore, the true signal $Y_{\text{true},\ 380}$ of spectrometer can be calculated by the equation below:

$$\begin{aligned}
Y_{true,\ 380}&=Y_{meas,\ 380}-Y_{stray,\ 380}\\
&=Y_{meas,\ 380}-[Y_{stray\ 380,550nm\text{-}650nm}\\
&\quad+Y_{stray\ 380,650nm-800nm}+Y_{stray\ 380,800nm-1080nm}]\\
&=Y_{meas,\ 380}-[R_{stray\ 380,550nm\text{-}650nm}\cdot Y_{550nm\text{-}650nm}\\
&\quad+R_{stray\ 380,650nm\text{-}800nm}\cdot Y_{650nm-800nm}\\
&\quad+R_{stray\ 380,800nm-1080nm}\cdot Y_{800nm-1080nm}]
\end{aligned}$$

This mathematical model can be easily used to calculate the correction results of stray light at UV wavelengths. As shown in Fig. 3, the spectral radiance results of the solar radiance on the ground-based verification site was corrected, the stray light effect of visible and infrared range on UV 380nm~400nm was significantly reduced.

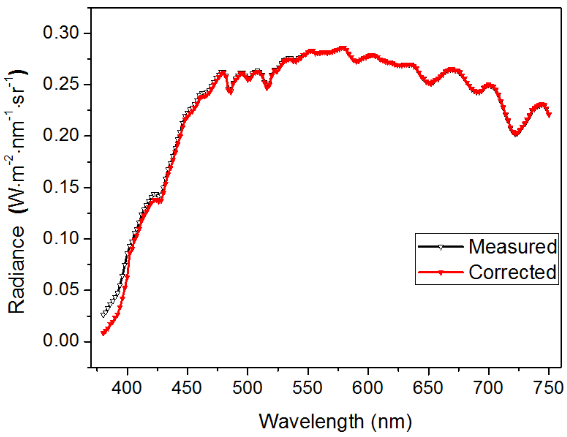

Figure 3. The measured result and corrected result of CR280 used in ground-based sites.

CONCLUSION

Here, a set of the bandpass filters with specific transmittances were used to measure UV stray light signals, and the mathematical correction model was established to realize the efficient evaluation and simple correction. The method with bandpass filter can be widely used due to simple experimental conditions and efficient work process for the continuously distributed wide-spectrum light sources.

ACKNOWLEDGMENTS

This work was supported by the National Key R&D Program of China, No. 2018YFB0504800 (2018YFB0504804).

REFERENCES

1. M. Jehle, A. Hueni, K. Lenhard, A. Baumgartner, M. E. Schaepman Detection and Correction of Radiance Variations During Spectral Calibration in APEX IEEE, Geoscience & Remote Sensing Letters, 12(5), 1023-1027, 2015.
2. S. W. Browm, B. C. Johnson, M. E. Feinholz, M. A. Yarbrough, S. J. Flora, K. R. Lykke, D. K. Clark, Stray-light correction algorithm for spectrographs, Metrologia, 40(1), 81-84, 2003.
3. Y. Zong, S. W. Brown, B. C. Johnson, K. R. Lykke, Y. Ohno, Simple spectral stray light correction method for array Spectroradiometers, Applied Optics, 45(6), 1111-1119, 2006.
4. S. G. R. Salim, N. P. Fox, W. S. Hartree, E. R. Woolliams, T. Sun, K. T. V. Grattan, Stray light correction for diode-array-based spectrometers using a monochromator, Applied Optics, 50(26), 5130-5138 , 2011.
5. S. Nevas, J. Gröbner, L. Egli, M. Blumthale, Stray light correction of array spectroradiometers for solar UV measurements, Applied Optics, 53(19), 4313-4319, 2014.