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THE DEVELOPMENT OF PORTABLE CALIBRATION LIGHT SOURCE AND TEMPERATURE CORRECTION ALGORITHM FOR IN-SITU RADIOMETER

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Abstract

With the requirements for SI traceability of satellite ocean colour products, it is crucial to reduce the absolutely radiometric uncertainties of spectroradiometers, which are used for in-situ measurements in ground-based validation sites and sea-based validation sites. In this work, two ways are provided to decrease the impact of environmental changes on lab-calibrated spectroradiometers, and therefore reducing the deviation of radiometers used for in-situ measurements. One of them is developing a portable light source for calibrating in-situ radiometers. The other one is investigating on mathematical correction algorithm of laboratory calibration coefficient for in-situ spectroradiometer.

Keywords: Calibration light source, Temperature correction algorithm, Spectroradiometers.

1 Introduction

Ocean colour is one of the Global Climate Observing System's essential climate variables, which is significant for analysing the impacts of climate change and the health of ocean (Fox et al., 2011). For the ocean-atmosphere system, the contributions of satellite sensor-measured top-of-the-atmosphere (TOA) radiances come from solar radiance scattered by atmospheric molecules and aerosols, sun and sky radiance reflected by the sea surface (either by the water surface itself or by foam from whitecaps), and finally from water-leaving radiance (Zeng et al., 2015). With the increasing requirements for SI traceability of ocean colour products, it is necessary to make comparisons between satellite-derived radiances and radiances measured at sea-based validation sites or the sea surface, in order to determine the gain or correction factor needed to convert a best estimate of a radiance into one that agrees with the radiance measured at the sea surface.

According to the in-depth analysis of spectroradiometer used for in-situ measurements, the main uncertainties are originated from lab-calibrated instruments transferring to the ground-based (sea-based) verification sites (Li et al., 2015). The origins of uncertainty include the environmental condition change, temperature change, the difference of the spectral distribution of the target light source, and the dynamic change of the light source. Generally, the radiance calibration is performed in laboratory, which is based on standard lamp (Woolliams et al., 2006), while the target light source of spectroradiometer in field is solar radiance . As is shown in Figure 1, both the spectrum and the intensity of standard lamp (1000 W) and solar radiance are different (Rottman et al., 2006). Recently, radiance calibration with different intensities is needed more urgent in Earth Observations, due to the large dynamic change of solar radiance measured at sea surface, it covers more than 4 orders of magnitude. The accuracy of the calibration and the performance of spectroradiometer are very important (Zhang et al., 2009). Therefore, calibration light source with adjustable intensity and mathematical correction algorithm for in-situ spectroradiometer should be developed.

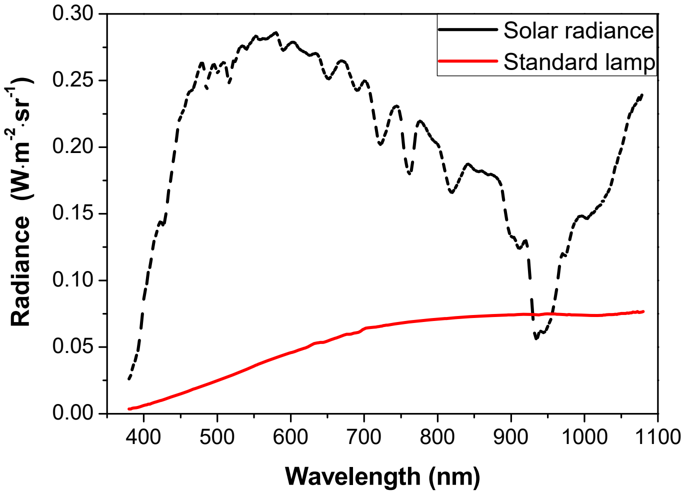

Figure 1 –The radiance measurement results of calibration lamp in laboratory and solar radiance in ground-based site

2 Methods and results

In this work, two ways are provided to decrease the impact of environmental changes on calibrated spectroradiometers: (1) Developing a portable light source for calibrating in-situ spectroradiometers; (2) Investigating on mathematical correction algorithm of laboratory calibration coefficient for in-situ spectrometers.

2.1 Calibration light source

The portable integrating sphere light source was technical designed and contained six adjustable 35W lamps in different directions. The lamps illuminate the inner surface of the integrating sphere and were diffused to illuminate through the opening. As is shown in Figure 2, every lamp has a fan to cool the heating temperature. The light source was portable and collected data automatically by computer remote controller. The portable light source provided larger dynamic range than standard lamp. The higher radiance reduced the impacts of intensity inconsistent of laboratory calibration light source and solar radiance.

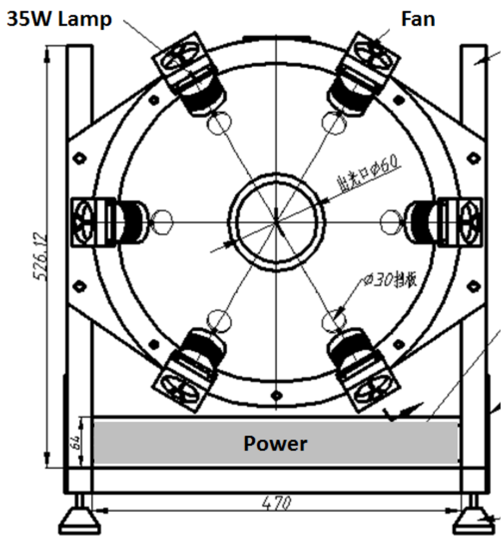

Figure 2 –The schematic diagram of integrating sphere light source

2.1.1 Stability and uniformity

The stability and uniformity are the most basic properties of calibration light sources. The stability of integrating sphere light source was tested by detector for 3 hours. The stability was is less than 0.021 %. The uniformity of the light source is measured by detector and lens with filter. They are placed on an electric displacement platform in front of the opening. The distance between the opening and detector was 10 cm. The equipment has a field of view of approximately 1°. The position of detector could be accurately controlled. The radiance of integrating sphere light was recorded automatically by LabVIEW software during whole work process. A range of 5 cm in diameter was measured. The results showed that the non-uniformity of the opening is just about 0.067 %.

2.1.2 Utilized for nonlinearity measurements

For satellite-measured ocean colour radiance, more than ~90 % of the TOA radiance is in the visible wavelengths. The wavelength range of 350 nm~900 nm is used for clean water, the wavelength range of 350 nm~1100 nm is used for medium turbid water, and the wavelength range of 350 nm~1600 nm is used for extremely turbid water. ASD Fieldspec spectrometers are commonly instruments for radiance measurements at sea surface. The nonlinearity of spectrometers is one of the directly reason for accurate in-situ measurement, since the difference of the spectral distribution of the target light source, and the dynamic change of the light source.

The luminous flux supplement method is used to study the linear characteristics of detectors. NIST has established the Beamcon III detector linear measurement system based on the supplement of luminous flux. The device is used to measure the linearity of the linear and indium gallium arsenide detectors within nine orders of magnitude of the silicon detector. The measurement uncertainty is 0.054 % (*k*=2), 0.08 % (*k*=2). The Canadian NRC has established a two-pass aperture detector linear measuring device that measures the linearity of the silicon detector in nine orders of magnitude with a measurement uncertainty of ±0.2 % (limited by the resolution of the electronics measurement). Salim et al. in NPL used the traditional double aperture method to test the irradiance values. It is measuring only one apertures (A or B) and the two apertures (A+B) simultaneously, and then calculate high-accuracy light intensity nonlinearity correction results (Salim et al., 2011).

Here, the integrating sphere light source with six adjustable 35 W lamps could be used to investigate on nonlinearity effects. The radiance intensity of light source may be adjusted by combining different lamps. The nonlinearity correction coefficients were calculated and analysed based on the experiment, respectively. In order to reduce stray light, all experiments were carried out in the dark environment. The dark signal, including the spectrometer offset, was subtracted automatically from the source signal for each measurement. The number of readings for averaging signals and spectrometer integration time were kept the same during all experiments.

The nonlinearity factor α is defined as $\{I(\text{A+B}) / [I(\text{A}) + I(\text{B})] - 1\}$. As is shown in Figure 3, the nonlinearity factors of ASD spectrometer are different in different wavelengths, especially in UV range. It was mainly due to the lower radiance and responsivity in UV range. The nonlinearity is within ± 0.025 % in the range of 500 nm~1100 nm under the lower radiance (less than 0.23 $W \cdot m^{-2} \cdot sr^{-1}$). However, the nonlinearity is about -2% under the brighter radiance. The nonlinearity of spectrometer could be corrected based on the experiment results.

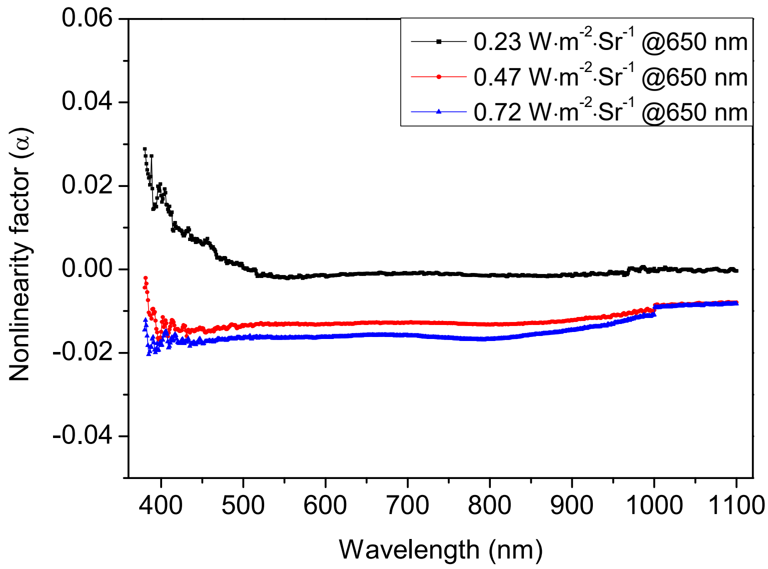

Figure 3 –The nonlinearity factor α of ASD spectrometer

2.2 Temperature correction algorithm

Ambient temperature change is a main uncertainty issue, since laboratory calibrations of in-situ spectroradiometers are performed at room temperature. The calibration coefficients determined under room temperature are not applicable to instruments used in the ground-based (sea-based) validation sites. Our previous research showed that dark current of the detector increased dramatically with the increase of temperature. The dark current of the CCD was formed by the transfer of hot electrons from the silicon to the conduction band, mainly including the dark current in the depletion region, the diffusion current in the free region, and the surface dark current. Although the surface dark current always dominated, as the temperature increased, the dark current in the depletion region, especially the diffused dark current, contributed more and more to the total dark current of the device, and was also affected by the temperature.

An experimental system for investigating the effects of ambient temperature on radiometric responsibility was established. It consisted of radiance light source, thermal chamber, thermometer, apertures and baffles. SVC HR-1024 is a series of field spectrometer, it was placed in thermal chamber, which simulated ambient temperature and humidity. The variation range of thermal chamber are -50°C~+100°C, (20%~98%) RH.

2.2.1 Temperature effects

As is shown in Figure 4, the deviations between measured results at different temperature and the calibration results at room temperature (24.5 °C) varied widely in the different wavelength ranges. This was mainly due to the detector consists of three parts, including: Si (350 nm~1000 nm); cooled InGaAs (1000 nm~1850 nm); extended InGaAs (1850 nm~2500 nm). The deviation between the measured value and calibration value in the range of 950 nm~1000 nm was as high as ±12.2 %. This spectral range was close to the band edge of the silicon, which was highly temperature sensitive, and the Si band edge moved to longer wavelengths as increasing temperature. The cooled InGaAs could effectively control the temperature of the detector to make it work normally. As the ambient temperature increased, the cooling effect of the InGaAs detector was affected (the optimal working temperature required for cooling is about 20 °C), and the deviation of measured and calibrated value results was about ±3 %.

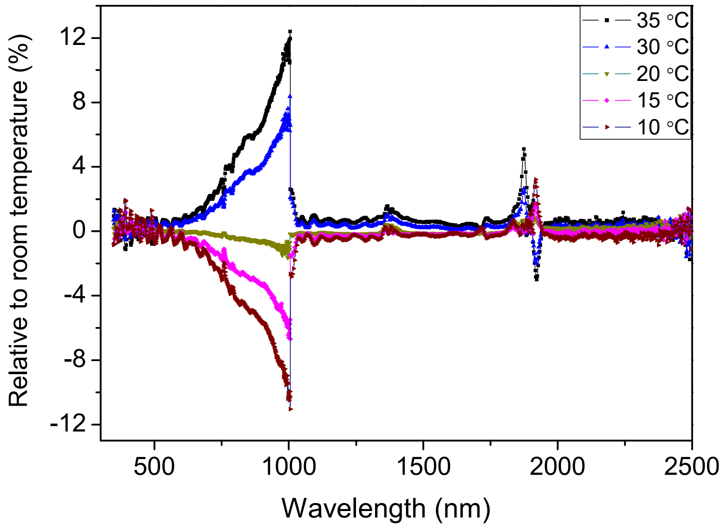

Figure 4 –Deviation of SVC HR-1024 response at different temperatures, relative to calibrated results

2.2.2 The mathematical algorithm

The traditional temperature correction usually based on the slope/intercept (S/B) algorithm. It established a linear function relationship between temperature and radiance at a certain wavelength. The equation could be expressed as $Y_m=a\times Y_s+b$, the slope a and the intercept b of the linear function were calculated by Least squares method. Then, functions between the different wavelengths and the corresponding slope and intercept were established separately. However, for different instruments, temperature effects on internal optical components of the spectroradiometer and the detector may be nonlinearity. The traditional S/B temperature correction method was limited in solving the nonlinearity problem.

A single-wavelength point-by-point temperature correction matrix algorithm was proposed, which directly established the functional relationship between the spectral response of each pixel and the temperature, and the full response band of the detector would be obtained by matrix calculation. It has following relationship:

$$\begin{bmatrix} I_{T0} \\ I_{T1} \\ \cdots \\ I_{Tm} \end{bmatrix} = \begin{bmatrix} I_{cal0} & 0 & 0 & \cdots & 0 \\ 0 & I_{cal1} & 0 & \cdots & 0 \\ \cdots & \cdots & \cdots & \ddots & \cdots \\ 0 & 0 & 0 & \cdots & I_{calm} \end{bmatrix} * \left(\begin{bmatrix} a_{00} & a_{01} & a_{02} & \cdots & a_{0n} \\ a_{10} & a_{11} & a_{12} & \cdots & a_{1n} \\ \cdots & \cdots & \cdots & \ddots & \cdots \\ a_{m0} & a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \begin{bmatrix} 1 \\ T \\ \cdots \\ T^n \end{bmatrix} \right) \quad (1)$$

where

I_{Tm} is the spectral response at experiments temperature T;

I_{calm} is the spectral response at calibration temperature T_0;

m is the pixel;

n is the order of fitting;

a_n is the temperature correction coefficient.

The matrix algorithm above can be calculated by MATLAB software due to the numerous data of all pixels.

2.2.3 Validation

Here, SVC HR-1024 was used to verify the temperature correction matrix algorithm. By using the formulas (1), each measured results at different temperatures can be corrected. The deviation of the whole wavelength range can be reduced to within ±1%. In addition, arbitrarily select an ambient temperature, such as 33 ° C. As is shown in Figure 5, the corrected result by matrix algorithm was very consistent with calibrated results.

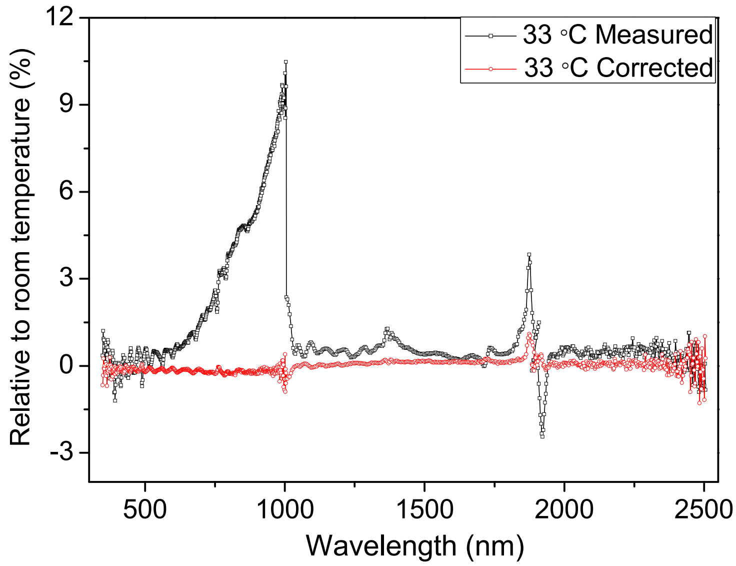

Figure 5 –Deviation between the corrected results and calibrated results of SVC HR-1024

3 Conclusions

The developed integrating sphere light source provided adjustable calibration light source for in-situ spectroradiometer. The stability was is less than 0.021 %, and the non-uniformity is just about 0.067 %. It could be also utilized for characterizing nonlinearity of spectrometers. The nonlinearity factors of ASD spectrometer are different under different radiance levels.

On the other hand, the sensitivity of SVC HR-1024 was affected by ambient temperature, which is dependent on wavelengths. The point-by-point temperature correction matrix algorithm is very effective for spectroradiometer. The deviation of the measured results at near-infrared wavelength was reduced from ±12.2 % to ±1 %. The correction method could be widely applied in ground-based validation sites and sea-based validation sites, which will greatly improve the accuracy of in-situ measurements.

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