MULTI-SATELLITES NORMALIZATION OF THE VISIBLE CHANNELS EQUIPPED ON THE FENGYUN-2 GEOSTATIONARY METEOROLOGICAL SATELLITES

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Abstract

After the successful launching of FY-2F on January 13, 2012, the total number of the in orbit operating FengYun-2 geostationary meteorological satellites reached three. Continuous observations from fixed position provide wealth data accumulation for calculating high update frequency surface bidirectional reflectance distribution function (BRDF). The normalization of the multiple geostationary satellites should be completed firstly. On the basis of the main plane symmetry of the directional reflective properties of the general surface targets, the normalization method was designed which was named Median Vertical Plane (MVP) method. The method could effectively solute the interference of surface directional reflectance characteristics without dependence on calibration. Take two geostationary satellites as the endpoint of one line segment, surface targets on the intersecting line of the segment's median vertical plane and the earth could be used as a normalization reference target (NRT). Observation on the NRT from the two satellites at the moment the sun passing through the median vertical plane could take the same observation zenith, solar zenith angle, and opposite relative direction angle. Thus the normalization coefficients could be obtained. Using the MVP method, the normalization coefficients between FY-2D, FY-2E and FY-2F were calculated. The results showed that the differences of the responsive between satellites could up to 10.1% (FY-2E to FY-2F); the differences of the output reflectance could up to 21.1 %(FY-2D to FY-2F). The verification method of the normalization results was also designed and the relative error was less than 0.2%.

Keywords: FengYun-2, geostationary satellites, visible channel, multi-satellite normalization, median vertical plane (MVP) method

1 Introduction

Geostationary meteorological satellites Fengyun-2s (FY-2s) were the first-generation geostationary satellite of China. There were 3 FY-2s currently in operation. FY-2D was launched on December 8, 2006, located at 86.5 degrees east longitude. FY-2E was launched on December 23, 2010, located at 104.5 degrees east longitude. FY-2E was launched on January 13, 2012, located at 112 degrees east longitude. The realization of the FY-2s multi-satellite observations expanded the scope of monitoring from space point; shorten the interval of observation from the time point; and reduced the risk of operation interruption due to mechanical errors from operational point. Continuous observations from their fixed position of each FY-2s could provide sufficient data accumulating for calculating high update frequency surface BRDF.

The main payload - visible infrared spin scan radiometer (VISSR) included 1 visible and 4 infrared channels [1],[2]. Quantitative application of multi-satellite observation data built on the basis of accurate calibration. The onboard calibration instruments of VISSR contained a half light path blackbody and a sun image monitor. VISSR and its calibration instruments had experienced rigorous laboratory and field vicarious calibration before launch [3]. The in-orbit calibration of infrared channels was relatively mature by the use of black body, GSICS and lunar vicarious calibration method. The sun image monitoring [4] and site vicarious calibration [5] of visible channels were held every year after-launch. But BRDF had always been the bottleneck question restricting inter and vicarious calibration accuracy of the visible channel. Taking into account the 6% vicarious calibration accuracy, the variation of the surface BRDF caused by the factors such as moisture content, temperature, vegetation coverings could not be ignored.

Since 1999, several field BRDF measurement campaign in Dunhuang had been carried out. The obtained observation data had been used to derive RossThick-LiTransit [6], Roujean [7] and RossThick-LiSparse [8] semi-empirical BRDF models. Among of them, LIU, J.J. derived the RossThick-LiSparse models by the use of the recently developed BRDF measurement device [9] in 2007, which was the currently used model for vicarious calibration of Fengyun series satellites [10], [11]. Comparison of BRF measured in situ and calculated from LIU, J.J.'s model during 2011 and 2013 were shown in Figure 1.

Figure 2 showed the spectral difference of the BRF in situ and from model. It varied from 6% to12%. That means the higher update frequency of the BRDF model, the closer the model to the actual. Compared to single-satellite, multi-satellites could offer more data to calculate the daily update surface BRDF. But the normalization should be realized at the first step.

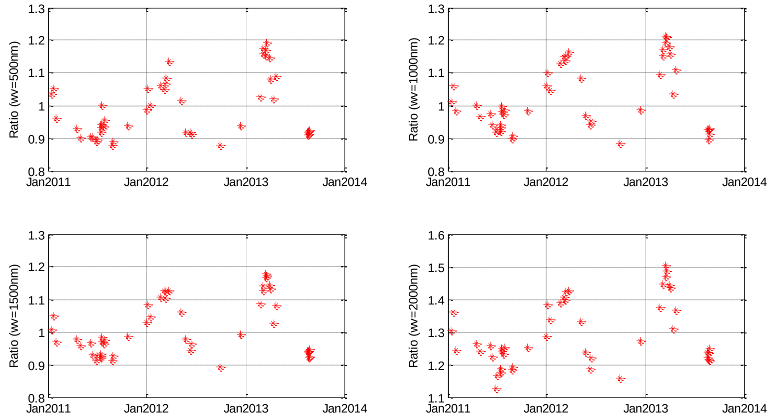

Figure 1 Ratio of BRF measured in situ and calculated from LIU, J.J.'s model during 2011 and 2013

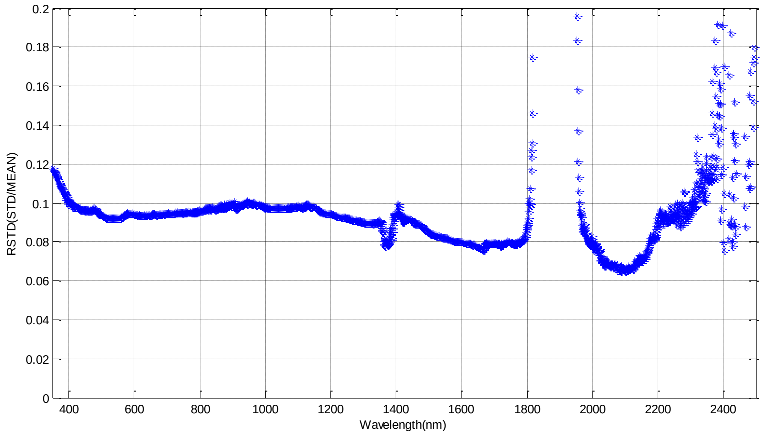

Figure 2 RSTD(STD/mean) of the ratio shows the spectral change of BRDF varies from 6% - 12%

2 Methods

2.1 MVP method

Differed from infrared channels normalization, visible channels normalization mainly faced the disturbance of the BRDF. The reflective properties of the BRDF could be described by three angles: the solar zenith angle, viewing zenith angle and relative azimuth angle. There were several wide used BRDF models, such as, Pinty-Verstraete physical model; symmetric of Walthall, symmetric sine Walthall empirical model; Hapke, Rahman and Ross-Li semi-empirical model. They all made use of relative azimuth by cosine calculation. That's to say the directional reflectance characteristics of the common surface target were symmetry along the principal plane. Accordingly a new method normalizing the visible channel of in-orbit multiple geostationary satellite could be designed, which was called MVP method.

Taking two geostationary satellites as the endpoint of a segment, surface target on the intersecting line of earth and MVP of the segment could be used as a NRT. Observation on the NRT by two satellites at the moment the sun passing through the MVP brought the same observation zenith, solar zenith, and opposite relative direction angle. The least squares linear fitting coefficient of the channel's output could be calculated by the formula shown in Equation (1) - (3).

$$V_e = V_d * S_{de} + I_{de} \qquad (1)$$

$$V_f = V_d * S_{df} + I_{df} \qquad (2)$$

$$V_f = V_e * S_{ef} + I_{ef} \qquad (3)$$

Where d, e and f respectively represented the satellite FY-2D, FY-2E, FY-2F; V represented the satellite output voltage, it could be replaced by reflectance to calculate the coefficients of reflectance; S were representative of the slope of the linear regression, I represented the linear fitting intercept. The AD quantitative relationship of the FY-2D, FY-2E and FY-2F's visible channel were basically the same, being designed as a non-linear response. The broadcast calibration lookup table of the three satellites and the experiment calibration look-up table obtained by 2011 site vicarious calibration experiment were shown in Figure 3. When voltage was taken as the output, the slope of the linear fitting coefficient represented the difference of responsivity of the visible channels; the intercept were on behalf of the difference of response to the dark current. When reflectance was taken as output, linear fitting coefficient represented reflectance difference of two satellites; the more the slopes close to 1and the intercept close to 0, the more accurate the calibration will be.

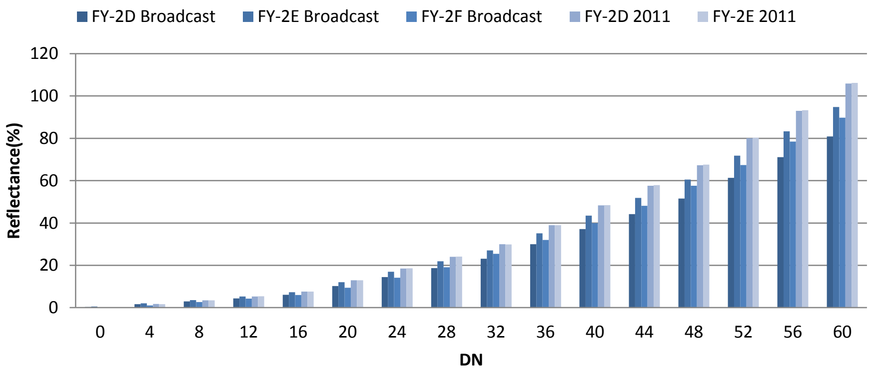

Figure 3 **Broadcast and the experiment calibration lookup table of FY-2D, FY-2E and FY-2F**

The NRT directional reflectance characteristics needed to be symmetry along the principal plane. And NRT's reflectance and BRDF should not change within the permitted scope in one hour. Figure 4 was the visible channel response function of FY-2D, FY-2E and FY-2F. The difference between the response function were obvious. The NRT spectral reflectance should be uniform. Snow and salt lake had this characteristic among general surface target. In winter, large areas lands of Northern

Hemisphere were covered by snow. It was an ideal NRT to carry out multi-satellite normalized.

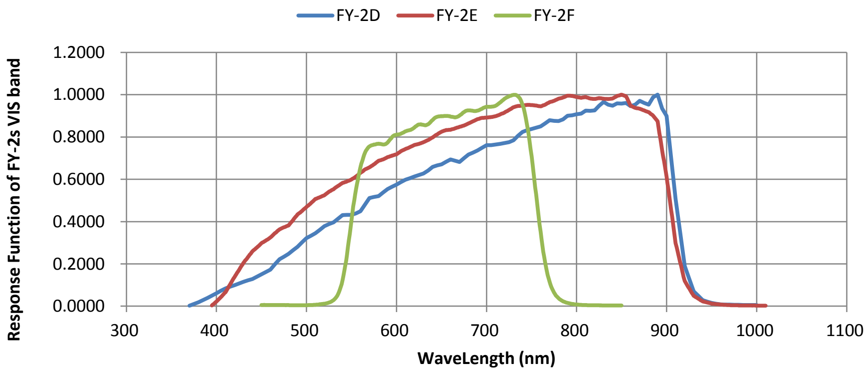

Figure 4 The visible channel response function and typical snow spectral reflectance

Due to the drift of the satellite's position, the positions of the NRT were slightly changing. Plus the observation time cannot happen to be the moment the sun passing through the MPV, the data filter were decided to control the accuracy within reasonable scope: difference of observation time should within one hour, differences of the NRT latitude and longitude should within 0.01 degrees, difference of the solar zenith angle, view zenith angle, relative azimuth angle (absolute value) should less than 0.1 rad. The correlation coefficient of single fitting should greater than 0.9.

2.2 Self-test

Normalizations between the satellites were carried out separately. If the three groups' normalization coefficients satisfy the formula (4), (5) which were obtained according to formula (1) - (3), it could be proved that the normalized calculation were accurate in a certain extent. Therefore, the formula (4), (5) were called self-test formula.

$$S_{de} = S_{df}/S_{ef} \qquad (4)$$

$$I_{de} = \left(I_{df} - I_{ef}\right)/S_{ef} \qquad (5)$$

2.3 Experiment validation

April, 2011 - August, 2011, the vicarious calibration experiment was held in Dunhuang radiometric calibration site. Vertical surface reflectance of 11 sampling points was measured during the noon. Sounding balloons and solar radiance were also observed. Totally 13 days' 17 effective calibration data were obtained. The FY-2D and FY-2E visible channel calibration lookup tables were determine and shown in Figure 3. The RSTDs of calibration coefficients were less than 3% and 5%. Using the experiment calibration lookup table, the FY-2D and FY-2E output reflectance were recalculated to obtain new normalized coefficients. If the fitting slope could closer to 1, validation could be made by each other.

3 Results and analysis

The observations by three satellites in the northern hemisphere winter were analyzed to calculate normalization coefficient. From December 1, 2012 to January 1, 2013, the normalization coefficients were calculated according to the formula (1) - (3). The results were shown below. Figure 5 and Figure 6 showed linear fitting results respectively based on the output voltage and the reflectance in 2 months.

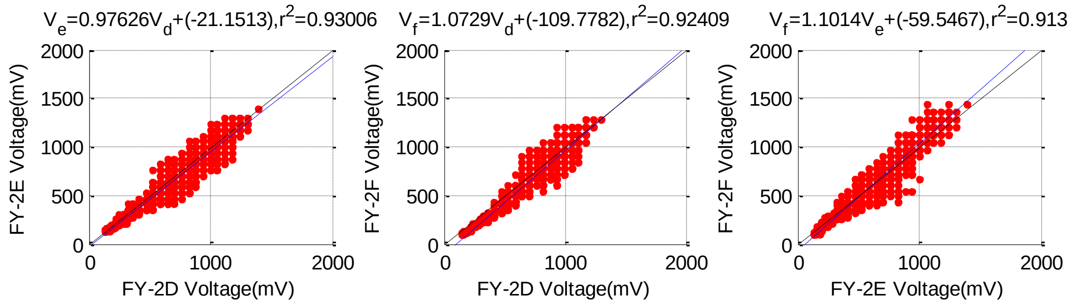

Figure 5 **Linear fitting results based on the output voltage of FY-2D, FY-2E and FY-2F**

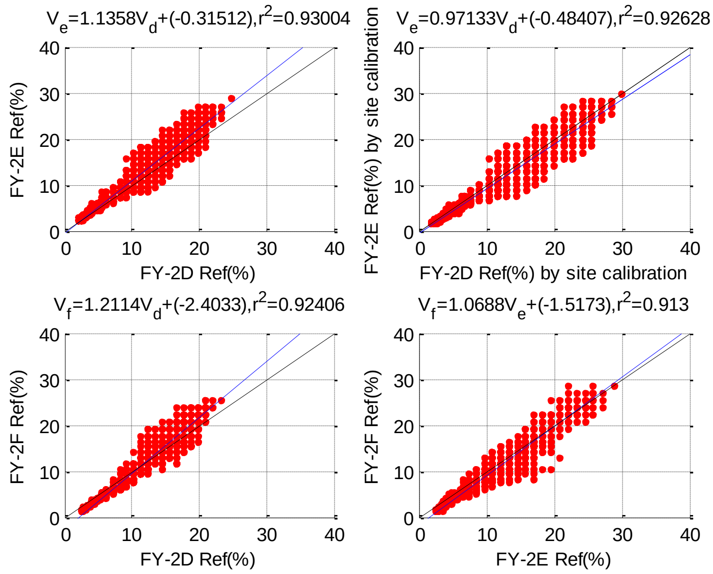

Figure 6 **Linear fitting results of FY-2D, FY-2E and FY-2F**

In Figure 6, the fitting slope reduced from 1.1358 to 0.9713. It meant that the reflectance difference of FY-2D to FY-2E reduced from 13.6% to 2.9% after using the site calibration look up table instead of the broadcast one. It could show the consistent result of site vicarious calibration and multi-satellite normalization.

Table 1 was the linear fitting results respectively based on the output voltage and the reflectance. The maximum difference of responsivity was between FY-2E and FY-2F, which was reached about 10.1%. Reflectance comparison results showed that the maximum difference was about 21.1%, which was between FY-2D and FY-2F. Table 1 also showed the relative errors of normalized slope calculated from the self-test formula were less than 0.2%. The absolute error of normalized intercept was less than 25mV (0.5% of the maximum output voltage), the corresponding reflectance was less than 0.6%.

	D to E	D to F	E to F	Self-test(D to E)
VS	0.9763	1.0729	1.1014	0.9741
VI(mV)	-21.1510	-109.7800	-59.5470	-45.6083
Vr^2	0.9339	0.9227	0.9115	
RS	1.1358	1.2114	1.0688	1.1334
RI(%)	-0.3151	-2.4033	-1.5173	-0.8290
Rr^2	0.9338	0.9227	0.9115	

Table 1 **Normalized coefficient and self-test results**

4 Conclusion

By the use of MVP method, it could be found that the responsivity difference between the satellites could up to 10.1% (FY-2E and FY-2F). And the maximum reflectance difference reached 21.1% (FY-2D and FY-2F). The fitting relative errors could be validated to be less than 0.2%. The reflectance was recalculated by the site calibration look-up table and the reflectance difference was reduced from 13.6% to 2.9%. MVP method was not relied on calibration and could provide a reference for the calibration validation pre and after launch.

5 Acknowledgments

This work was supported by nature science foundation of China (40705011, 41271373) and special fund for public welfare industry (meteorology) of China (GYHY200906036).

6 References

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