中国科学院空天信息创新研究院
Aerospace Information Research Institute (AIR)
Chinese Academy of Sciences (CAS)

Modelling of TOA reflectance for stable sites in northwestern China and its calibration application

Lingling Ma, Yongguang Zhao

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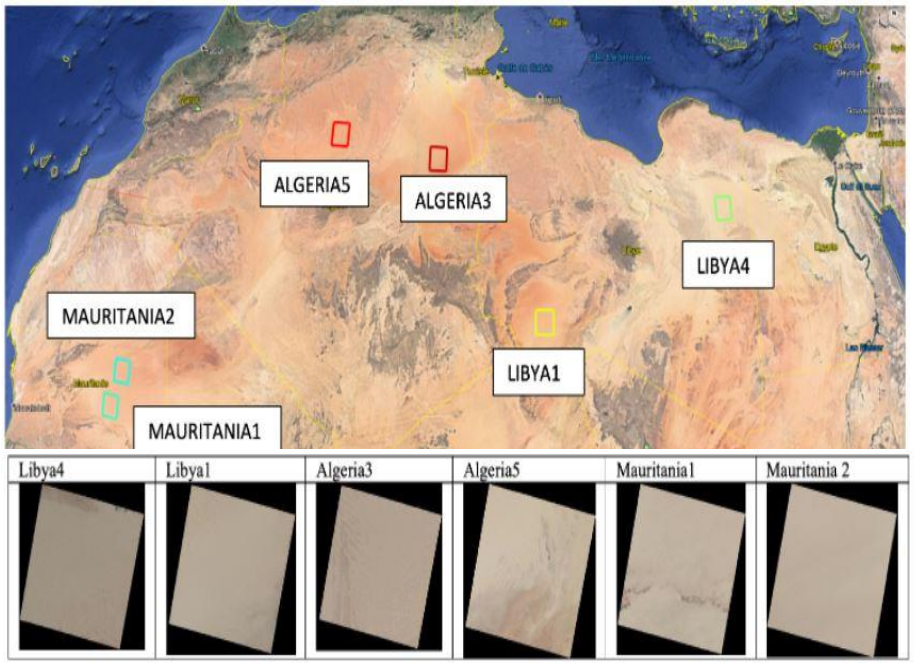
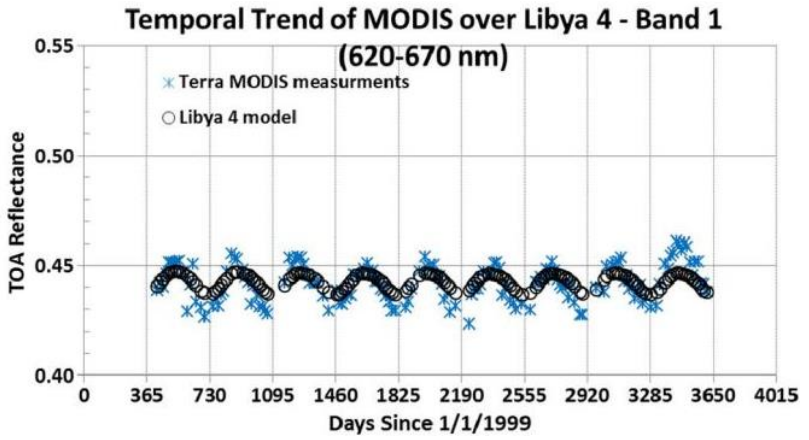
1.Background

- PICS plays an important role in satellite sensor performance evaluation and radiometric calibration. 6 PICS sites were recommended in the IVOS-19 meeting.
- The analysis and modeling of PICS characteristics have always been of great concern, and PICS TOA reflectance models have been constructed for satellite radiometric calibration.

CEOS has recommended 6 PICS in the North Africa Region





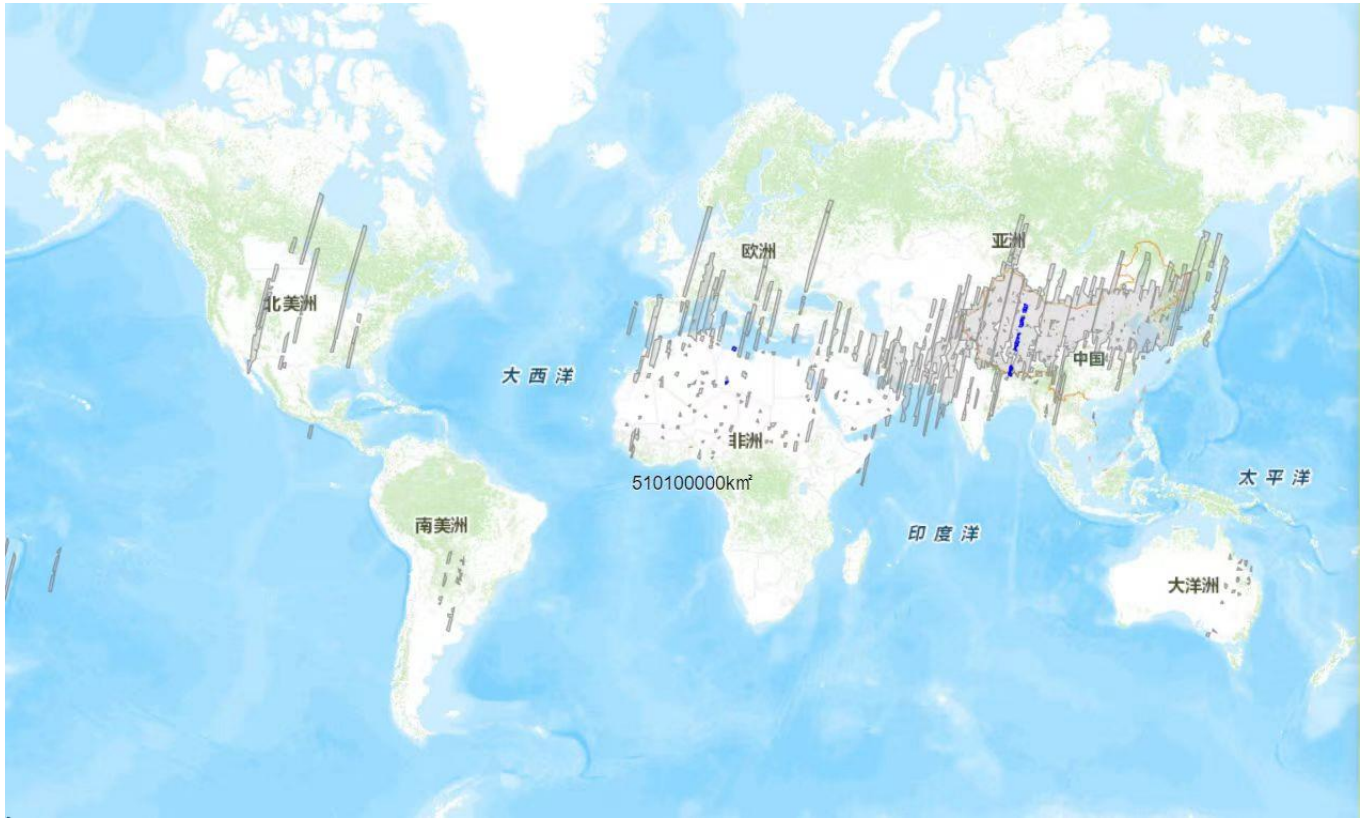
TOA reflectance model for Libya 4:

$$\rho_{Libya4}(\lambda, SZA) = k(\lambda)\rho_h(\lambda)[\alpha(\lambda)(SZA)+1]$$

The model can well characterize the variation of TOA reflectance with observed geometry.

1.Background

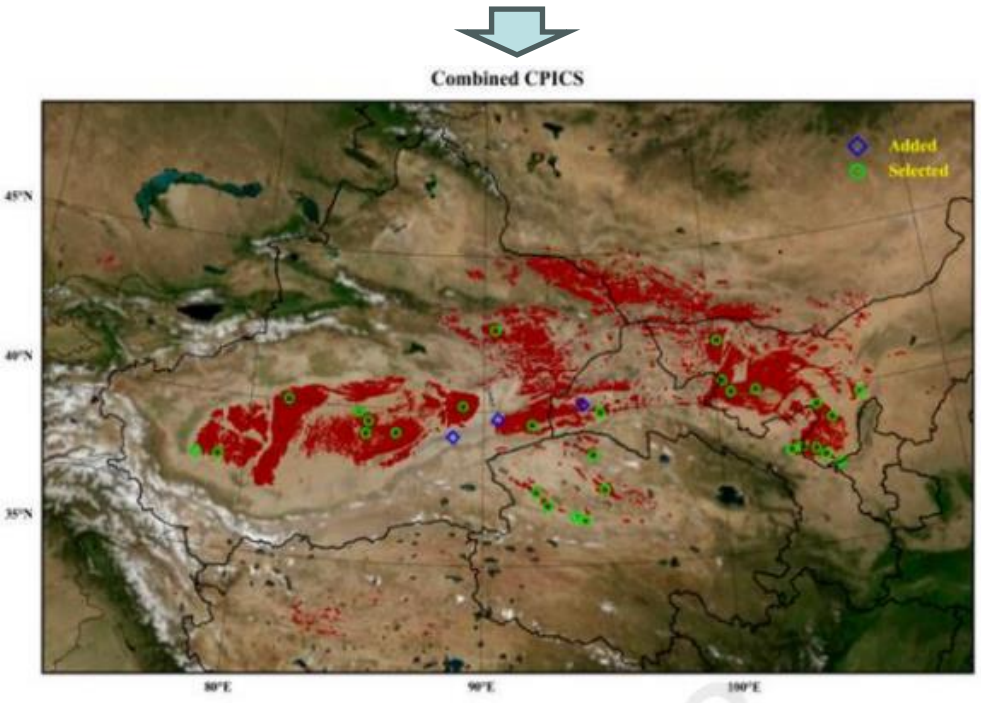
- The PICS TOA reflectance model has great potential in achieving high-frequency calibration, characterized by low cost and high stability of calibration results.
- China's medium to high resolution satellite imaging is mostly concentrated within and around China, and PICSs in the Sahara Desert region cannot be used.



Imaging coverage of GF-5B AHSI sensor (2021.9-now)

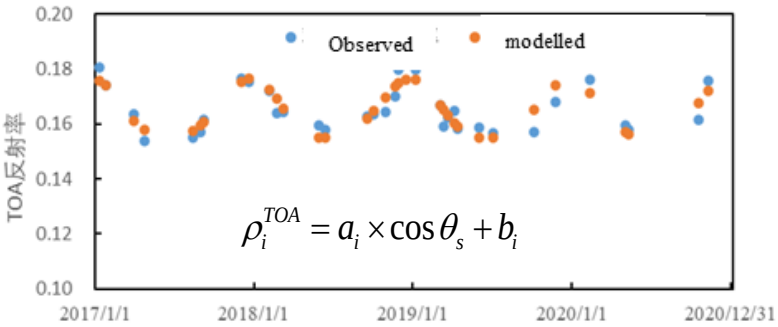
1.Background

- Relatively stable characteristics: spatial uniformity better than 3%, temporal stability better than 10%, site size greater than 3km * 3km.
- Although the surface/atmospheric stability is not as good as PICS, it has high radiometric stability.



Invariant site in Northwestern China

(Hu, et al., 2020, RS)



Landsat-8/OLI B1

Comparison between simulated and observed reflectance

(Yang et al,2021)

Liu et al, 2019:

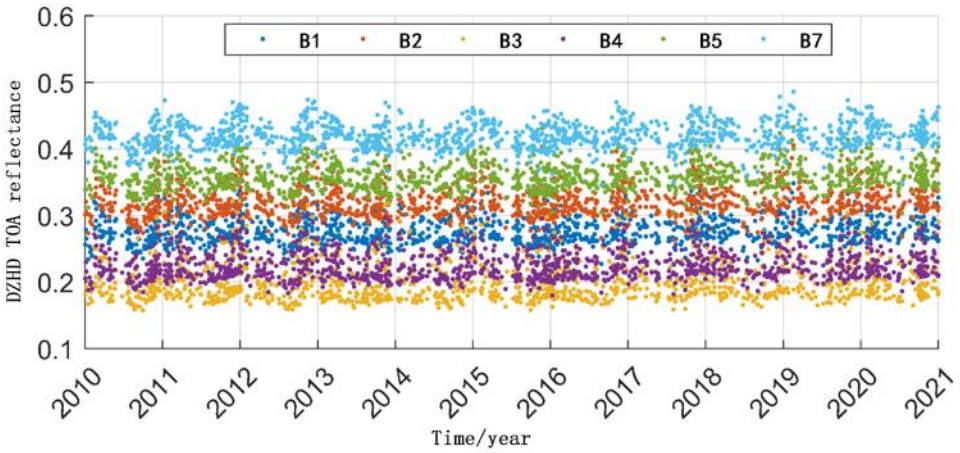
$$R(\theta_s,\theta_v,\varphi) = f_{iso} + f_{vol}K_{vol}(\theta_s,\theta_v,\varphi) + f_{geo}K_{geo}(\theta_s,\theta_v,\varphi)$$

The classic surface semi-empirical BRDF model need to be improved for without considering the impact of surface/atmospheric variation.

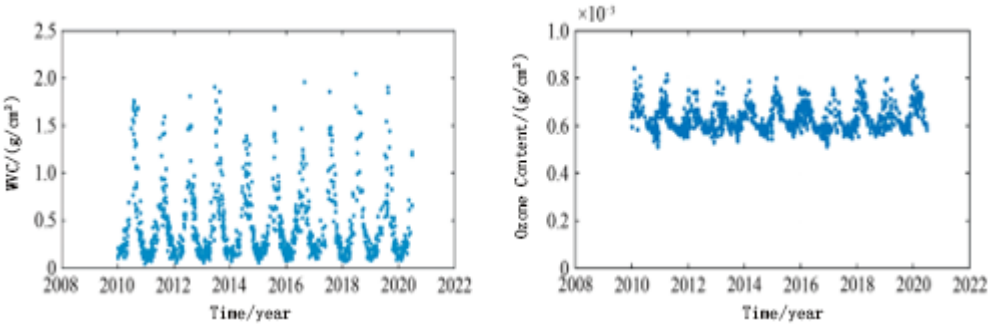
2. Modelling of TOA reflectance for stable site in northwestern China

2.1 Characteristic analysis of stable sites in northwestern China

- Using Aqua/MODIS and ECMWF Reanalysis data to analyze the variations in TOA reflectance of stable sites in China, the criteria for choosing stable sites were determined.



MODIS TOA Reflectance Time Series



Atmospheric Data Time Series

Data category	Product	Date range
Surface reflectance	Sentinel-2A/B	2020.3-10
	MCD43A4(V006)	2010-2020
Atmosphere parameters	ECMWF/ERA5	2010-2020
	ECMWF/EAC4	
TOA reflectance	MYD02IKM	2010-2020
	MYD03	
	MYD35 L2	

Criteria for choosing **stable site**

① Site's area>3km×3km;

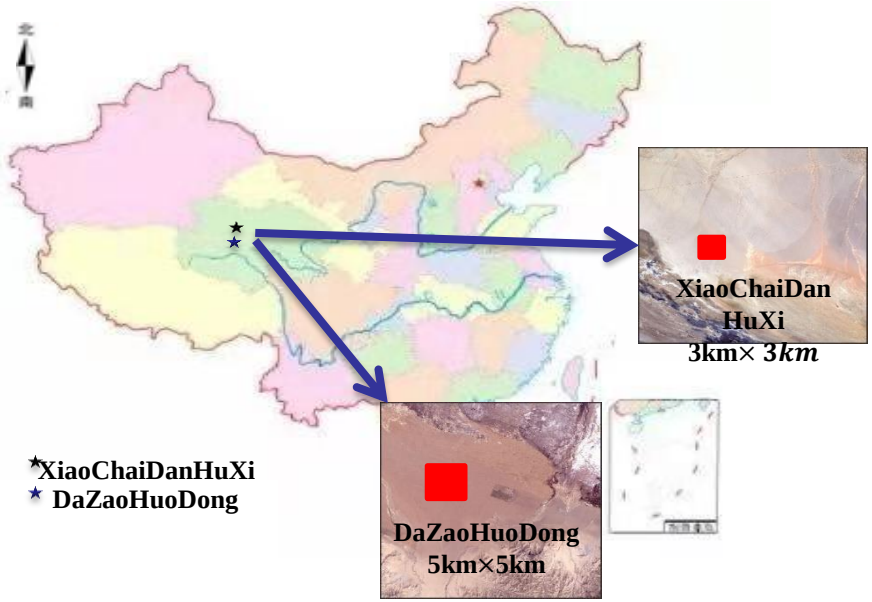
② Cloud coverage<35% ;

③ Spatial uniformity<3% ;

④ Temporal stability<10%。

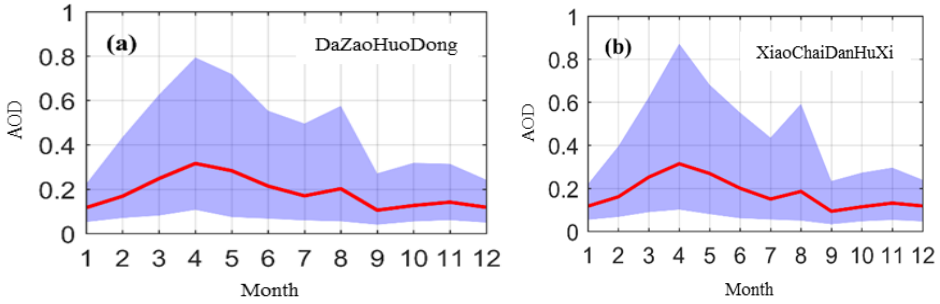
2. Modelling of TOA reflectance for stable site in northwest China

2.1 Characteristic analysis of stable sites in northwestern China



Research Area Selection

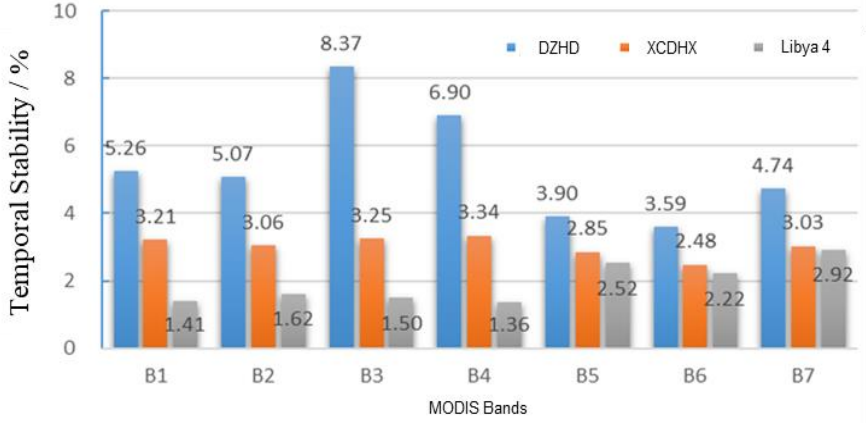
Monthly Average AOD 2010~2020 BJT 11:00 (550nm)



Based on the characteristics analysis:

- ✓ Most stable sites in China have lower temporal stability than the PICS.
- ✓ Atmospheric data have apparent seasonal trend, which should be put into consideration when building TOA reflectance model.

MCD43A4(V006)Ground Reflectance Product(2010-2020)



Uniformity by using Sentinel-2A/B L2A Product(2020/3-2020/10)

Site	Blue	Green	Red	NIR
DaZaoHuoDong	2.23%	2.05%	1.78%	1.76%
XiaoChaiDanHuXi	1.74%	1.36%	1.19%	1.20%

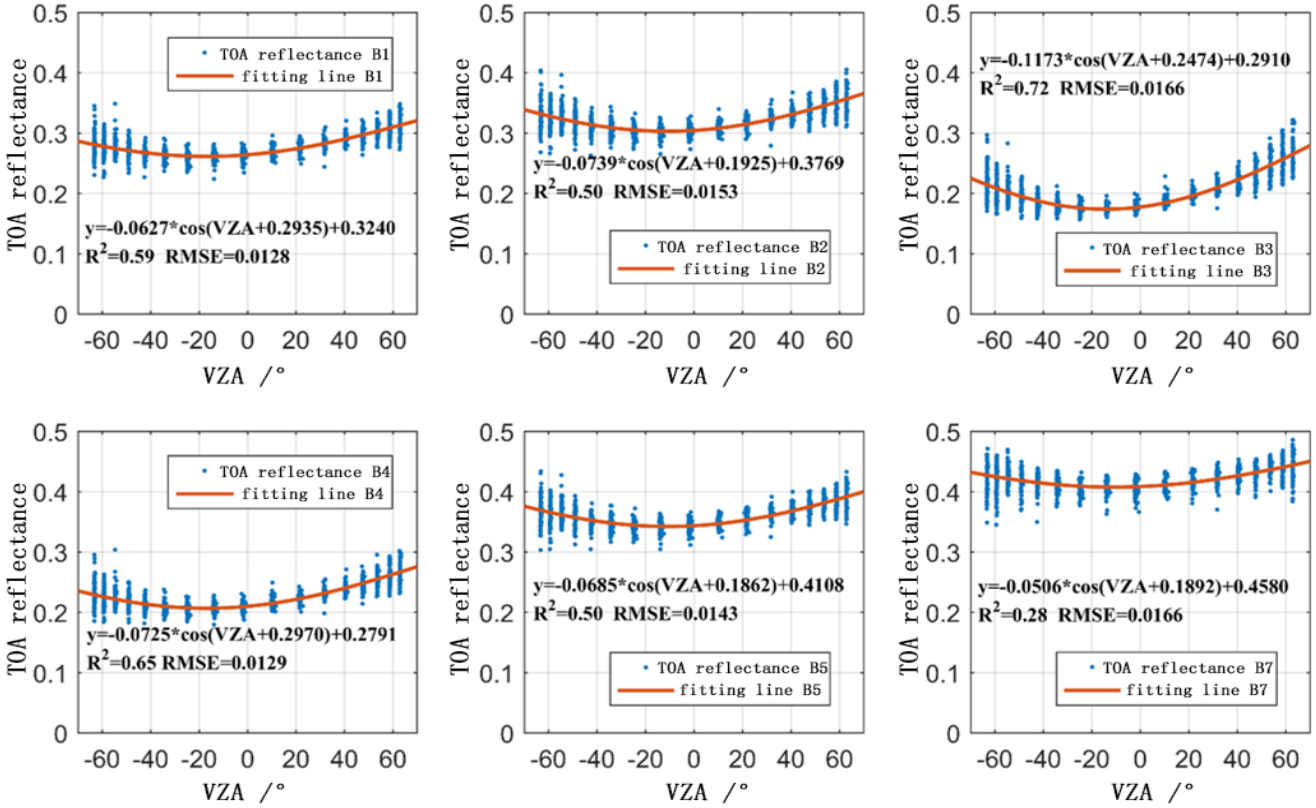
2. Modelling of TOA reflectance for stable site in northwest China

2.2 Building TOA Reflectance Model-with viewing geometry as variable

- **TOA reflectance of stable sites at different VZA**

The variation of TOA reflectance with observed zenith angle in the DaZaoHuoDong is fitted using cosine function based on time-series MODIS TOA reflectance.

$$\rho^{\mathrm{TOA}} = a_1 \times (\cos\theta_v + a_2) + a_3$$



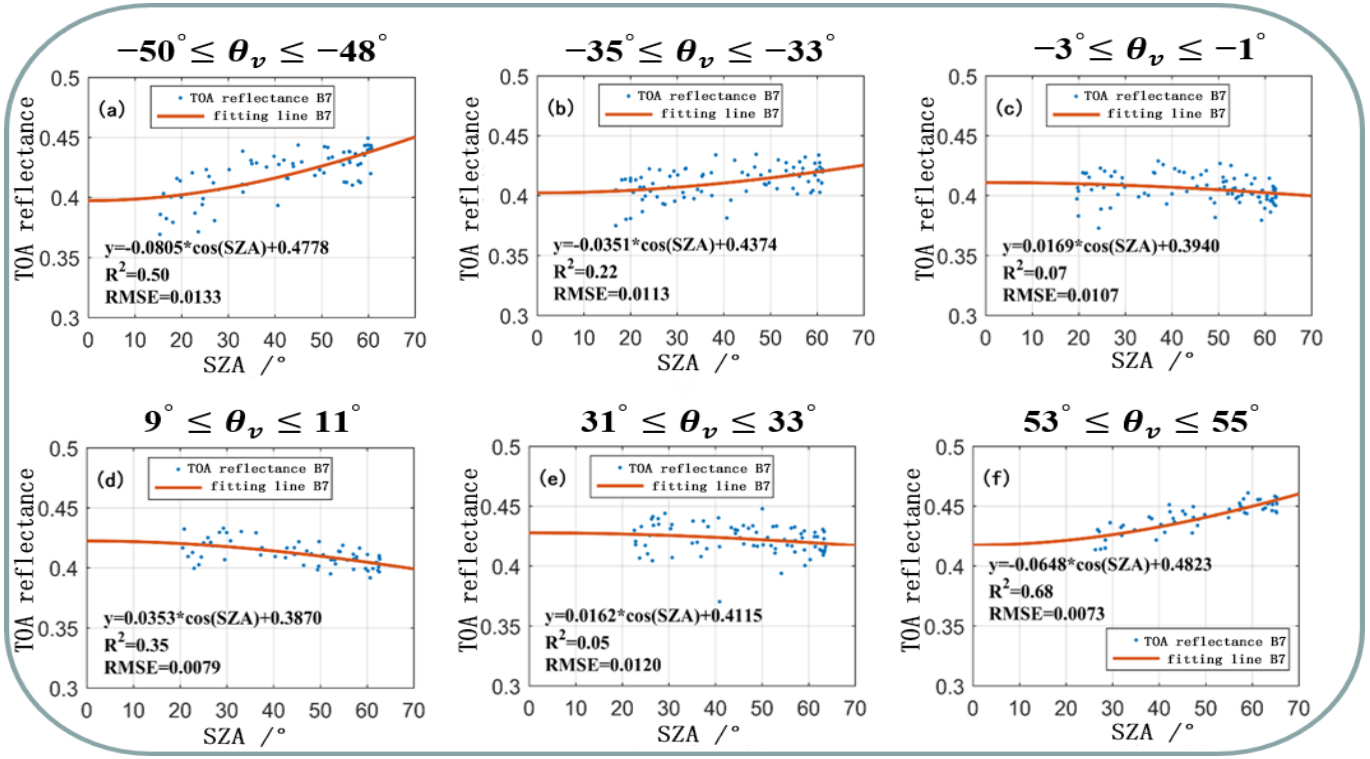
2. Modelling of TOA reflectance for stable site in northwest China

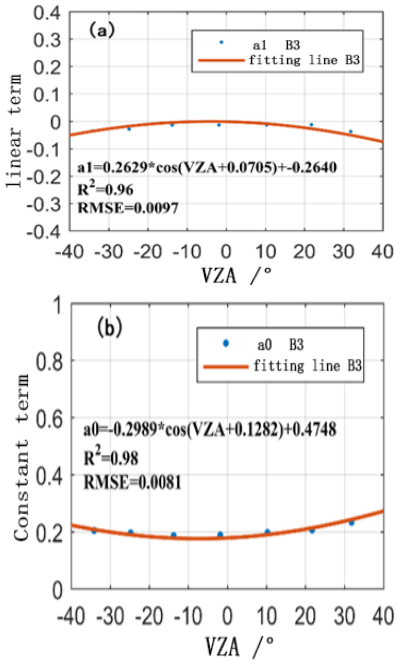
2.2 Building TOA Reflectance Model- with viewing geometry as variable

- **TOA reflectance of stable sites at different SZA**

The effect of observing zenith angle on TOA reflectance is obvious, therefore, we analyze the variation of TOA reflectance with the VZA when the solar zenith angle is fixed. Then, the model with SZA and VZA were determined.

$$\rho^{\mathrm{TOA}} = \cos\theta_s \times (a_1 \times (\cos\theta_v + a_2) + a_3) + a_4 \times (\cos\theta_v + a_5)$$





2. Modelling of TOA reflectance for stable site in northwest China

2.2 Building TOA Reflectance - with viewing geometry as variable

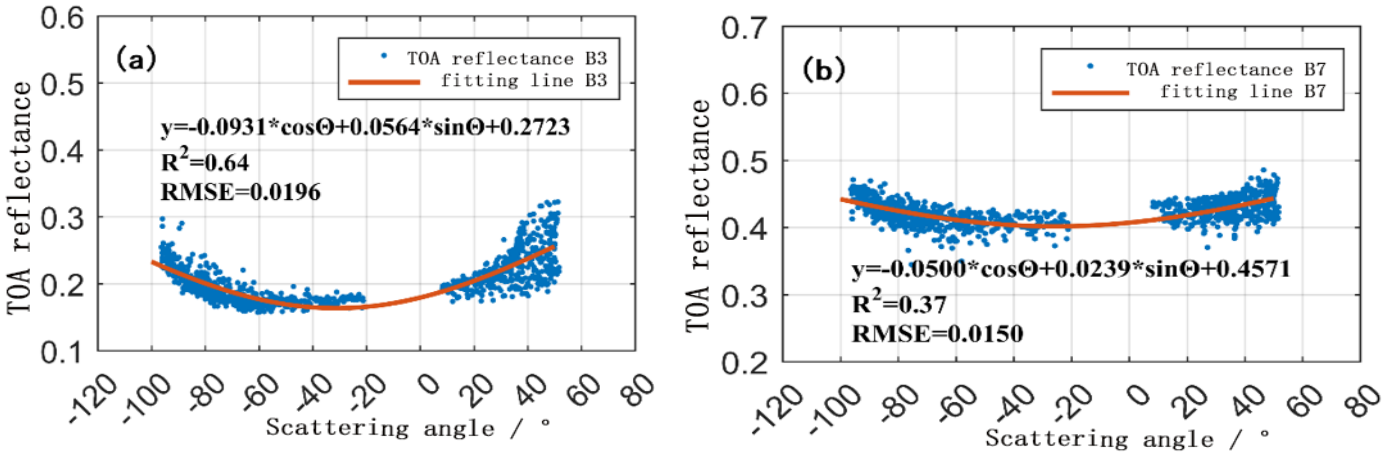
- **TOA reflectance of stable sites at different scatter angle**

The scattering angle is introduced into the model to characterize the multiple scattering interactions between the atmosphere and the surface.

$$\cos\Theta = \cos\theta_s \times \cos\theta_v + \sin\theta_s \times \sin\theta_v \times \cos(\varphi_v - \varphi_s)$$

ROSS-LI Scattering Function

$$K_{RT} = \frac{(\pi/2 - \Theta)\cos\Theta + \sin\Theta}{\cos\theta_s + \cos\theta_v} - \frac{\pi}{4}$$



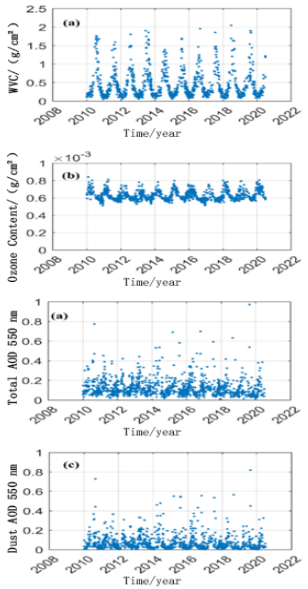
TOA Reflectance under different scatter angle(DaZaoHuoDong Site)

$$\rho^{\mathrm{TOA}} = \frac{\cos\theta_s \times (a_1 \times (\cos\theta_v + a_2) + a_3) + a_4 \times (\cos\theta_v + a_5)}{a_6 \times \cos\Theta + a_7 \times \sin\Theta + a_8}$$

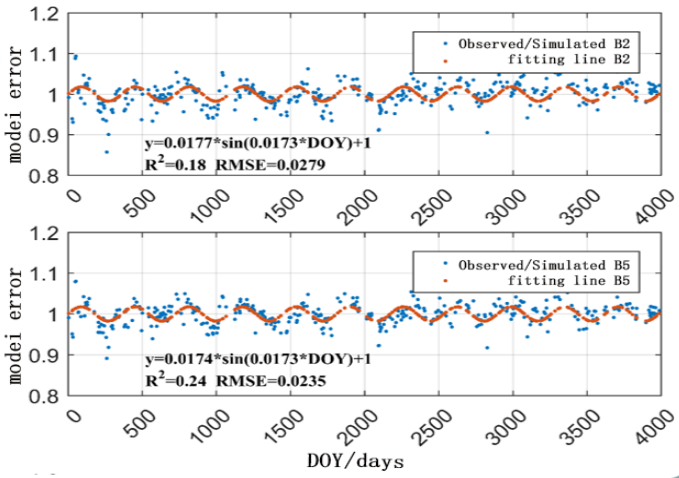
2. Modelling of TOA reflectance for stable site in northwest China

2.2 Building TOA Reflectance - with atmospheric parameter as variable

- After considering the effect of VZA, SZA and scattering angle on TOA reflectance, the residual of the model exhibits seasonal periodic changes. Then, temporal change was modeled by using day of year (DOY) as a parameter in the TOA reflectance model.



Periodic changes in atmospheric parameters



Applicable conditions for the model

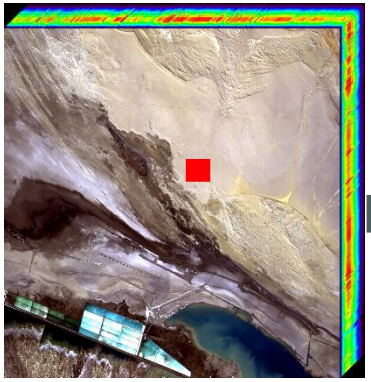
Sources	constraint condition
VZA	$-35^\circ < \theta_v - \theta_s < 35^\circ$
Scattering angle	$-35^\circ < \theta_v - \theta_s < 35^\circ$
Precipitation type	Precipitation type=0
Snow density	Snow density<0.16g/cm^3
cloud cover	Total cloud cover<0.80
AOD	Total AOD<0.40(500nm)
WVC	Total CWV<2.00g/cm^2

$$\rho^{\mathrm{TOA}} = \left(\frac{\cos\theta_s \times (a_1 \times (\cos\theta_v + a_2) + a_3) + a_4 \times (\cos\theta_v + a_5)}{a_6 \times \cos\Theta + a_7 \times \sin\Theta + a_8} + a_9\right) \times \left(a_{10} \times \sin\left(\frac{2\pi}{365} \times DOY\right) + 1\right)$$

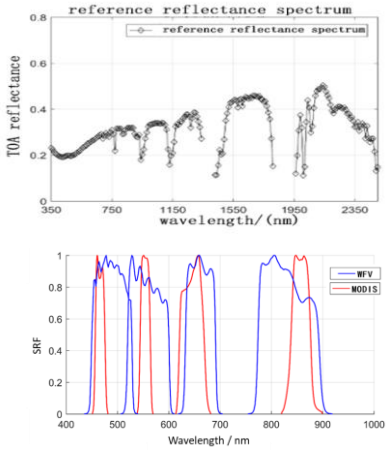
2. Modelling of TOA reflectance for stable site in northwest China

2.2 Building TOA Reflectance -Spectral expansion

- With the help of hyperspectral satellite observation data, the reference TOA reflectance spectrum corresponding to a stable site is selected. Then, the TOA spectral reflectance is obtained by processing the reference reflectance using a scaling factor. The channel reflectance model is extended to the spectral reflectance model.

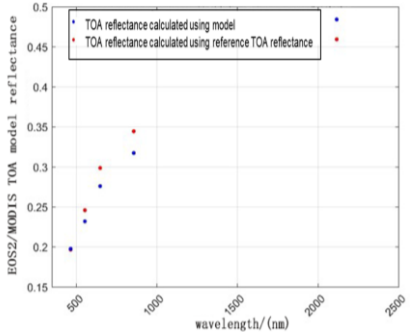


GF5B/AHSI hyperspectral data

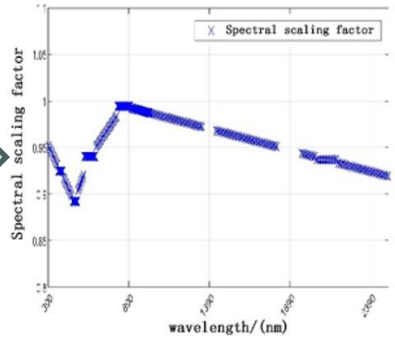


TOA reflectance model

$$\rho^{\mathrm{TOA}}(\theta_s, \theta_v, \Theta, DOY)$$



Channel TOA reflectance calculated based on reference TOA reflectance spectra and TOA reflectance models, respectively

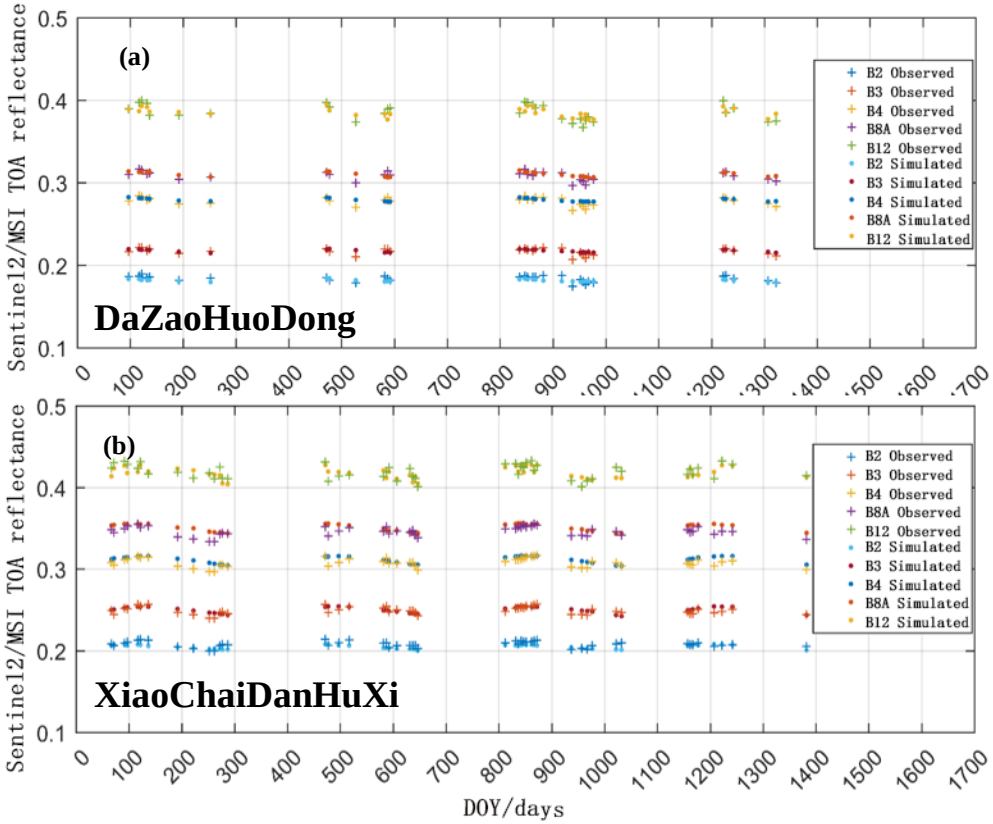


Scaling factor used to process the reference TOA reflectance to obtain modelled TOA reflectance

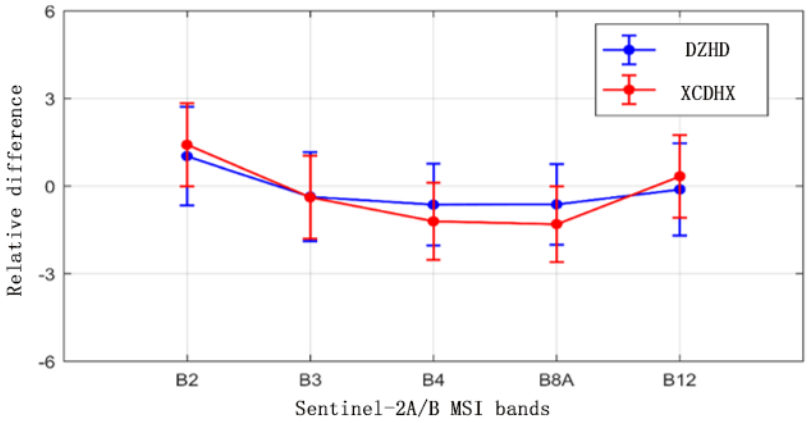
3. Validation and calibration application

- **Sentinel-2A/B MSI(2018~2021：DaZaoHuoDong 31 samples, XiaoChaiDanHuXi 49 samples)**

  The relative difference between simulated TOA reflectance of Sentinel-2A/B MSI and observed TOA reflectance is within ± 3%.



Comparison of Sentinel-2A/B MSI（a）DaZaoHuoDong (b)XiaoChaiDanHuXi



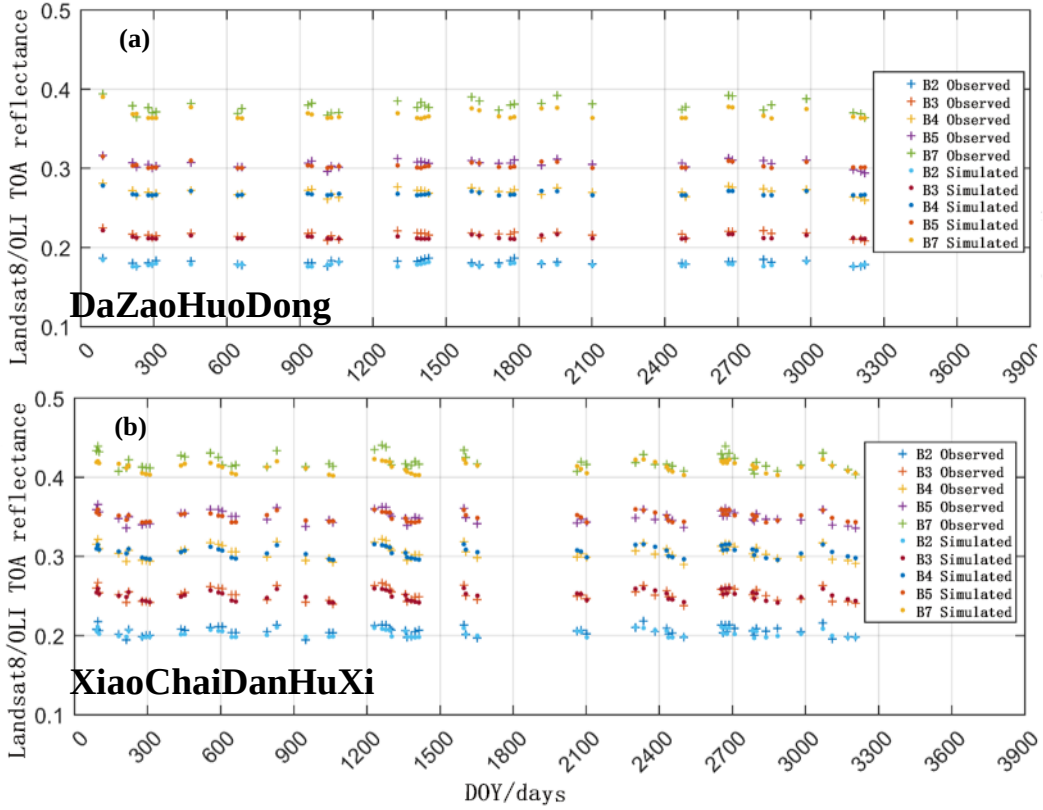
The relative difference between simulated TOA reflectance of Sentinel-2A/B MSI and observed TOA reflectance

Site	Sample	Average Relative Error	Absolute Relative Error	RMSE
DaZaoHuoDong	31	< ±1.02%	<1.69%	<0.0061
XiaoChaiDanHuXi	49	< ±1.41%	<1.70%	<0.0061
Total	80	-		

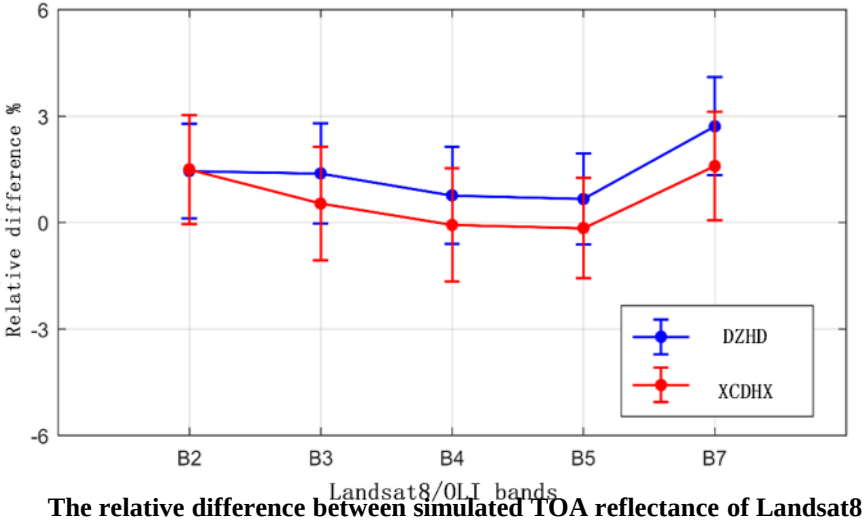
3. Validation and calibration application

■ **Landsat8/OLI (2013~2021： DaZaoHuoDong 31 samples, XiaoChaiDanHuXi 49 samples)**

- The relative difference between simulated TOA reflectance of Landsat8/OLI and observed TOA reflectance is within ± 3%;



Comparison of Landsat8（a）DaZaoHuoDong (b)XiaoChaiDanHuXi

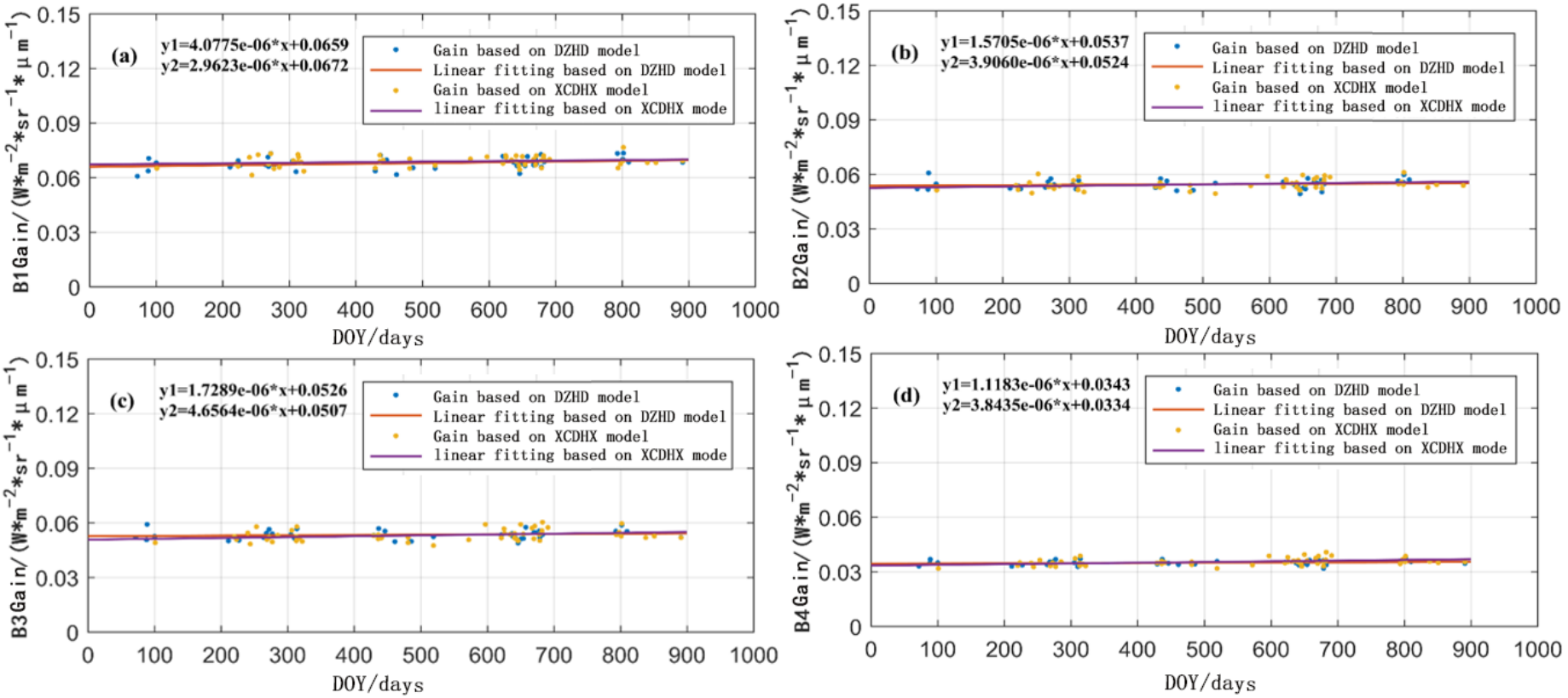


The relative difference between simulated TOA reflectance of Landsat8 and observed TOA reflectance

Site	Sample	Average Relative Error	Absolute Relative Error	RMSE
DaZaoHuoDong	37	< ±1.45%	<2.77%	<0.0044
XiaoChaiDanHuXi	60	< ±1.59%	<1.89%	<0.0049
Total	97		-	

3. Validation and calibration application

■ **Application of GF6/WFV high frequency radiometric calibration**



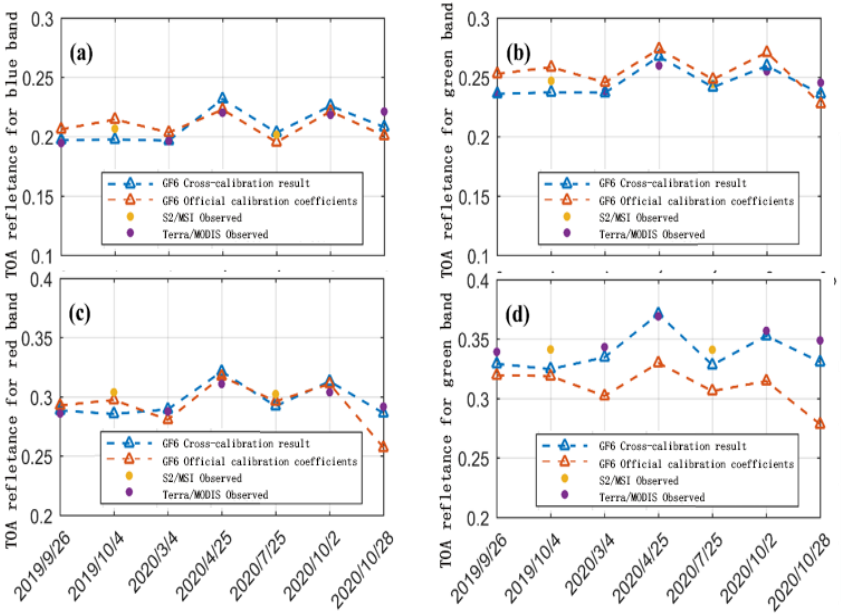
GF6/WFV时间序列定标系数（a）B1（b）B2（c）B3（d）B4

GF6/WFV was calibrated 91 times during 2019-2021

3. Validation and calibration application

■ Application of GF6/WFV high frequency radiometric calibration

- When limiting the overpassing time difference to <20 min and VZA<15°, GF6/WFV's TOA reflectance is compared with Sentinel-2/MSI and Terra/MODIS.
- For specific sites, the TOA reflectance of GF6/WFV sensor calculated using the stable site calibration coefficient is more consistent with MODIS and Sentinel-2, with a relative difference of less than 5% compared to the official coefficients.



The difference between GF6/WFV TOA Reflectance and reference satellite

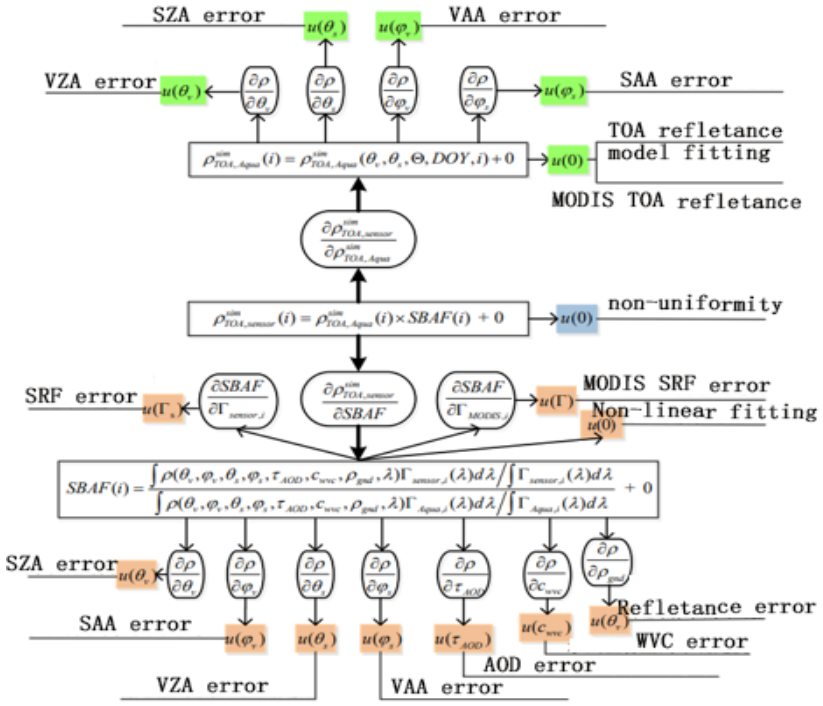
Relative difference	Sentinel2/MSI（2 scenes）		Terra/MODIS（5 scenes）	
	GF6/WFV Calibration based on stable sites	GF6/WFV Official calibraiton coefficients	GF6/WFV Calibration based on stable sites	GF6/WFV Official calibraiton coefficients
Blue	2.64%	3.45%	3.22%	4.28%
Green	2.51%	3.15%	1.85%	5.77%
Red	4.73%	2.12%	1.96%	4.22%
NIR	4.31%	8.39%	2.47%	12.11%

Comparison of TOA reflectance of difference sensors（a）Blue band（b）Green band（c）Red band（d）NIR band

3. Validation and calibration application

■ Uncertainty analysis of TOA reflectance model

- Considering the uncertainty caused by factors such as model input parameter errors, model fitting, and spectral expansion, the uncertainty of TOA reflectance model associated with each factor was analyzed based on Monte Carlo simulation.
- The analysis results shows that the uncertainty of the model ranges from 3.5% to 4.0%.



The uncertainty transmission link of the TOA Reflectance model

Simulated TOA reflectance's uncertainty / %
（Using GF6/WFV as example）

	B1	B2	B3	B4
VZA	0.07	0.07	0.04	0.01
VAA	0.11	0.03	0.01	0.03
SZA	0.11	0.01	0.01	0.03
SAA	0.23	0.04	0.01	0.06
MODIS	2.00	2.00	2.00	2.00
Model fitting	2.26	2.22	2.05	1.93
Spectral expansion	2.25	2.50	2.37	2.25
Combined uncertainty	**3.77**	**3.90**	**3.72**	**3.57**

4. Conclusion

- The TOA Reflectance model suitable for stable sites in China was built by introducing scattering angle and characterizing the effects of viewing angle and seasonal variance of atmospheric parameters. The uncertainty analysis for this model is around 4%. The TOA reflectance calculated by the model was compared with Landsat-8 and Sentinel-2A/2B, the relative error is mostly within ±3%.
- There are many similar stable sites in northwest China, and modeling work for these sites is still ongoing. Calibration applications based on these models will also be carried out, which will help improve the calibration frequency of Chinese satellites.
- In future SITSat-based applications, the TOA reflectance model of stable site (or PICS) can play an important role, such as analyzing the reference target characteristics in cross calibration, and correcting angle differences in cross calibration.

THANK YOU FOR YOUR ATTENTION!

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www.aircas.ac.cn

Lingling Ma

mall@aircas.ac.cn