Dragon 5 Cooperation

Cross-calibration of high-resolution optical satellite with SI-traceable instruments over RadCalNet sites

Chinese PI: Prof. Chuan-rong Li, AIR-CAS, CHINA
European PI: Prof. Philippe Goryl, ESRIN-ESA, ITALY

Outline

1. Project Overview

2. Current research results

3. Work Plan and Schedule

1、 Project Overview

Team Composition

European PI **Prof. Philippe Goryl** ESA, ITALY	**Chinese PI** **Prof. Chuan-rong Li** AIR-CAS, CHINA

	Co-Investigator	Affiliation
European	Dr. Marc Bouvet	ESTEC -ESA
	Prof. NigeL Fox	NPL
Chinese	Prof. Caihong Dai	NIM
	Prof. Shi Qiu	AIR-CAS
	Prof. Lei Ding	SITP-CAS
	Prof. Xiaobing Zheng	AIOFM-CAS
	Prof. Xin Ye	CIOMP-CAS

1、 Project Overview

■ **Objective：**

- Improve accuracy of cross-calibration for medium and high-resolution satellite sensors
- Build the radiometric benchmark transfer chain based on RadCalNet sites

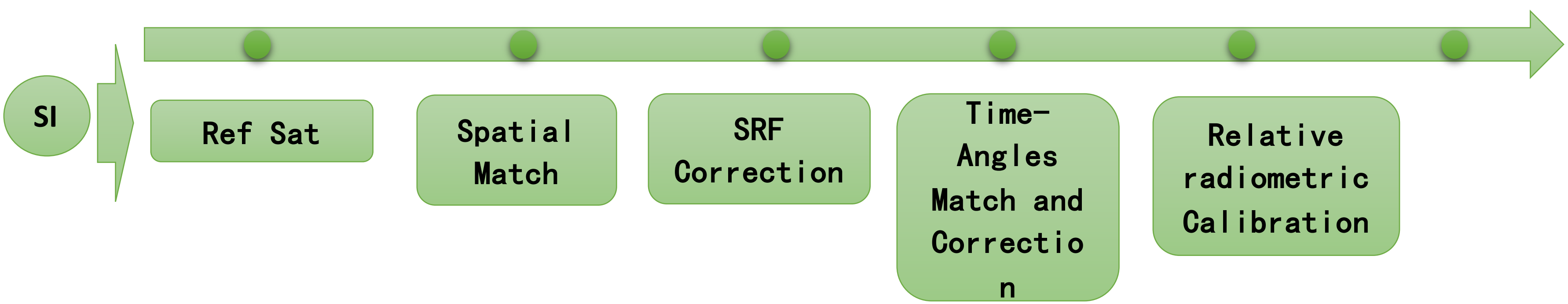
■ **Challenges：**

- Low pass-over frequency
- More measurement uncertainty due to multiple sensors, long chain
  - Imaging angles, sensor characteristics, correction models

1、 Project Overview

The success criteria of the project:

- Achieve a benchmark transfer chain with uncertainty better than 2%
- No less than 3 co-authored papers



1、 Project Overview

■ Technical and scientific approach and method：

①**Develop cross calibration workflow**

SI-traceable sensor → RadCalNet TOA product → target sensors

- Main components:
  - Alignment model (site and sensor specific)
  - Cross calibration model

② **Focus on RadCalNet sites as proof-of-concept**

- Baotou site

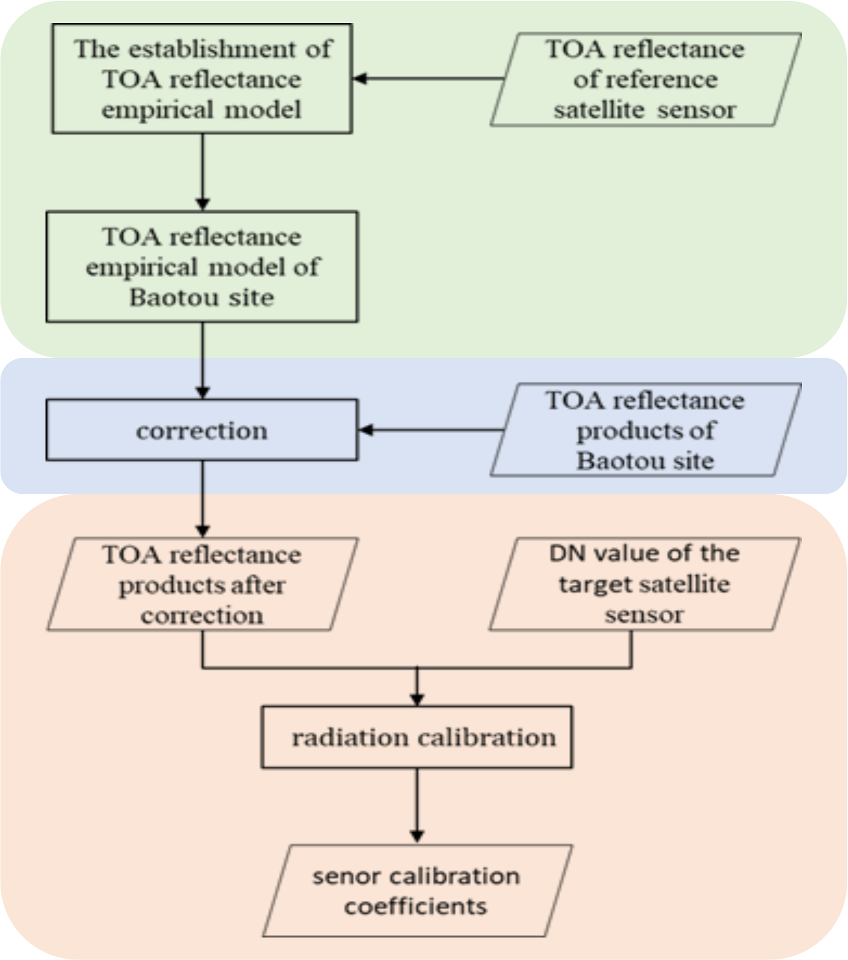
③ **Experimentally evaluate the proposed method**

2、Current work

- 1st year (2020.07-2021.06)
  - Investigation of literature and useful data;
  - Mutual cooperation to make detailed technical scheme, clear task division and practical cooperation mechanism;
  - Make collection and processing scheme of satellite image and ground measurement data;
- 2nd year (2021.07-2022.06)
  - Collection of available RadCalNet standard radiation product; Satellite data collection and processing, including Landsat-8, Sentinel-2A/B, GF series, ZY series, and SV series;
  - Develop RadCalNet TOA reflectance correction method using Landsat-8 and Sentinel satellite data with high radiometric calibration accuracy;
- 3rd year (2022.07-2023.06)
  - Develop the radiometric benchmark transfer calibration method based on RadCalNet sites;
  - Uncertainty analysis on full chain of the radiometric benchmark transfer calibration;
  - Application demonstration of the proposed radiometric benchmark transfer calibration method, using Chinese & European moderate- and high-resolution satellite data;

2、Current research results

Cross Calibration Workflow



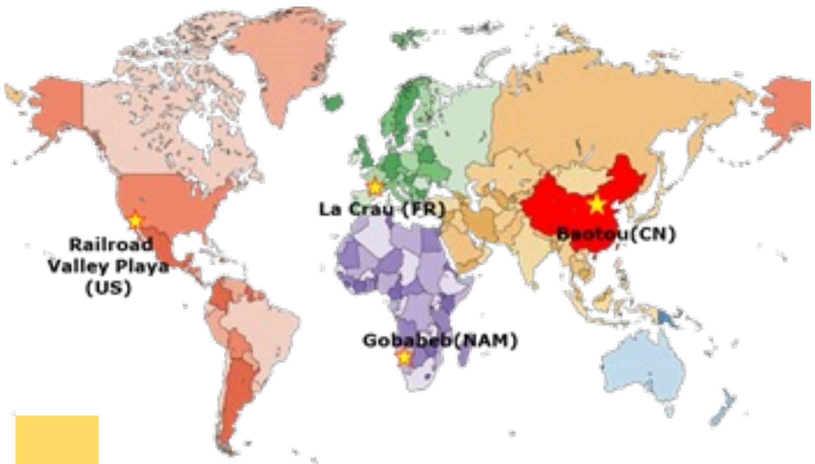
"Reference-Based Site TOA Alignment Model"

"Site TOA Alignment"

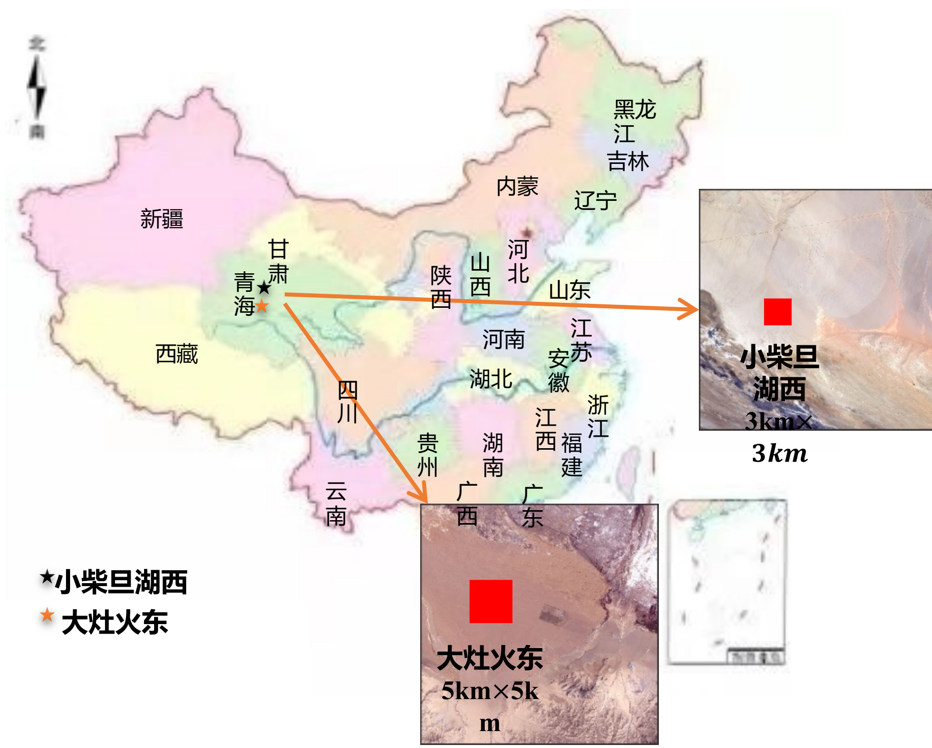
Target Calibration from Adjusted Model

2、 Current research results

Case study 1 (Baotou)



Case study 2 (Golmud)



2、 Current research results

Case study 1

Developing the Satellite-Derived TOA Model

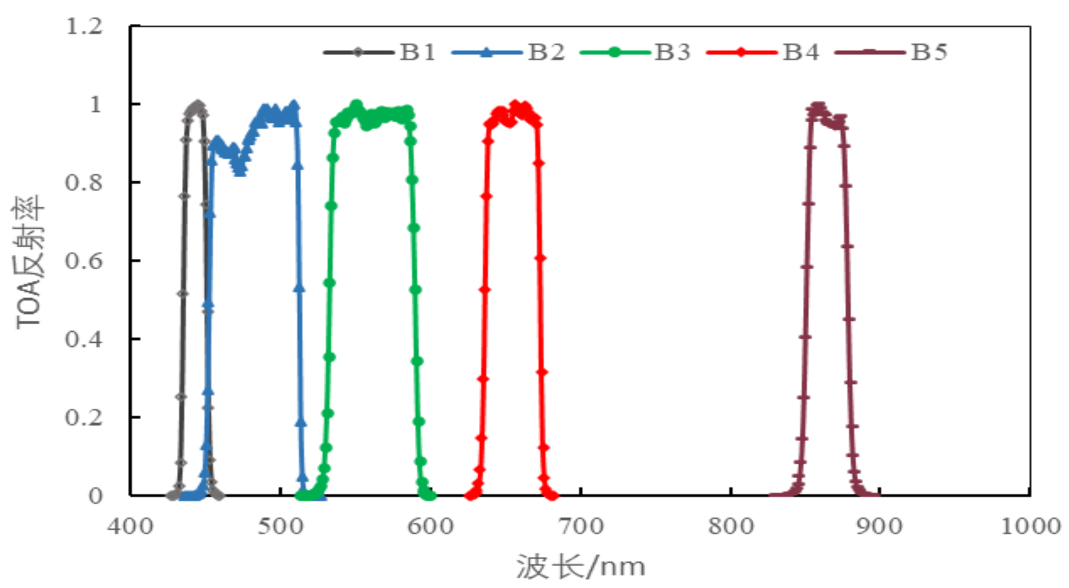
① Reference Selection

②Data Selection

③ Data Analysis

④ Model Construction

Satellite-Derived TOA Empirical Model



2、 Current research results

- The TOA empirical model was built based on the long-time sequence observation data from a high-precision radiation reference satellite(Sentinel 2) of Baotou sand field.

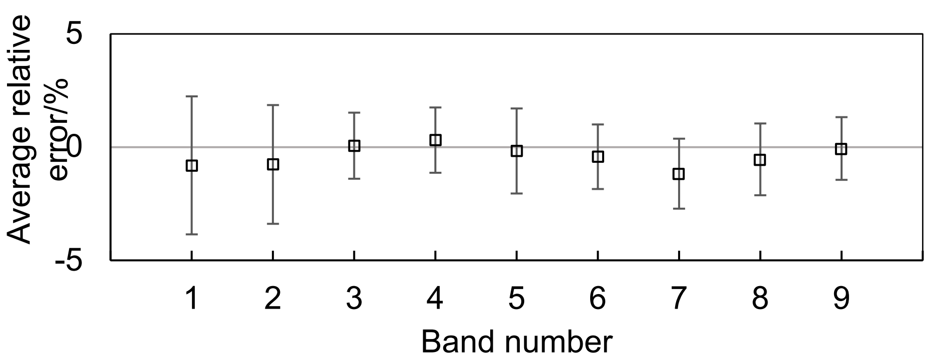


Fig.3 Average relative error between model simulated TOA reflectance and Sentinel-2 observed TOA reflectance

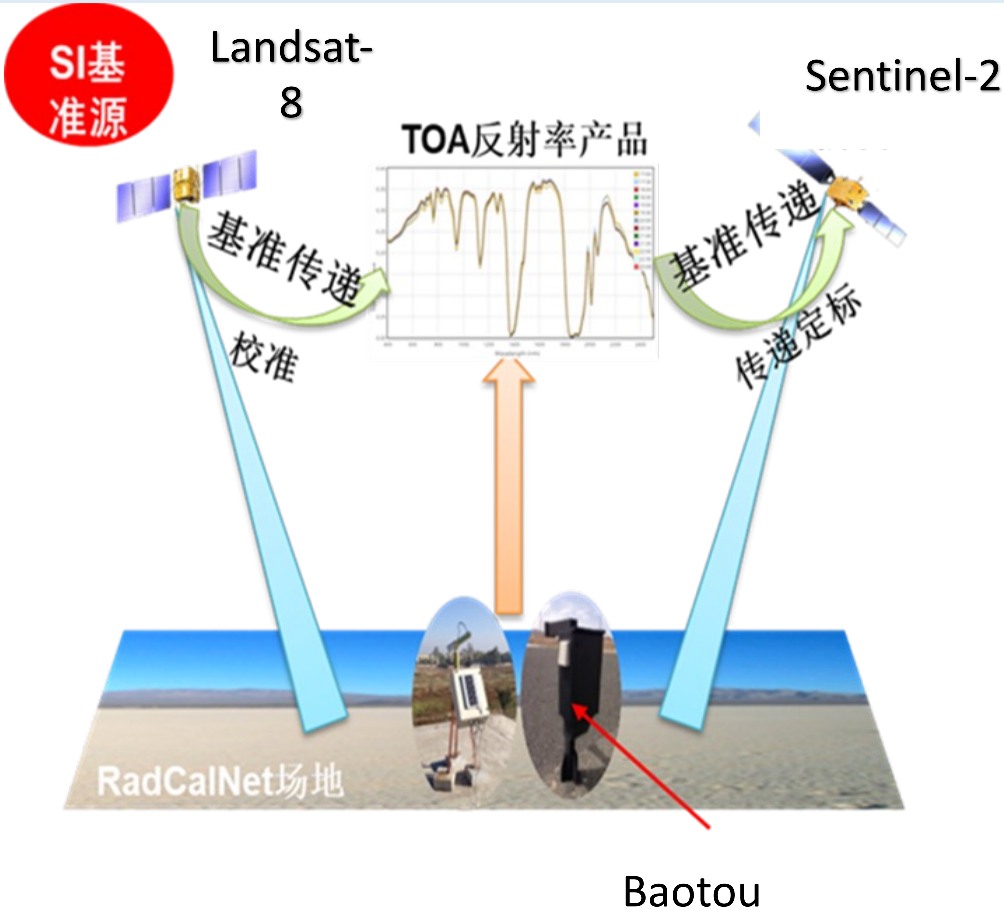
The accuracy of Baotou sand target TOA reflectance model established in this study is quite good, which the average relative difference between the predicted values of the model and the observed values of Sentinel-2 satellite is less than 2% (the blue band is less than 3%).

Table 1 Average relative error between model simulated TOA reflectance and Sentinel-2 observed TOA reflectance

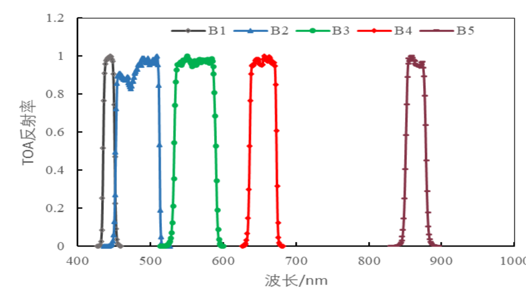
No.	1	2	3	4	5	6	7	8	9
Channel No.	B1	B2	B3	B4	B5	B6	B7	B8	B8A
Average relative error%	0.81	0.76	-0.06	-0.31	0.17	0.42	-1.17	0.54	0.06
RMSE of relative error	2.95	2.62	1.46	1.44	1.88	1.43	1.55	1.59	1.38

2、 Current research results

- **Application: The model was used to correct TOA reflectance products of Baotou sand field, to reduce the errors of TOA reflectance products of Baotou site, and will be used to improve the accuracy of satellite to be calibrated.**

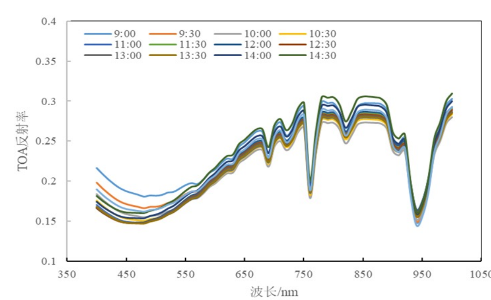


Satellite-Derived TOA Empirical Model



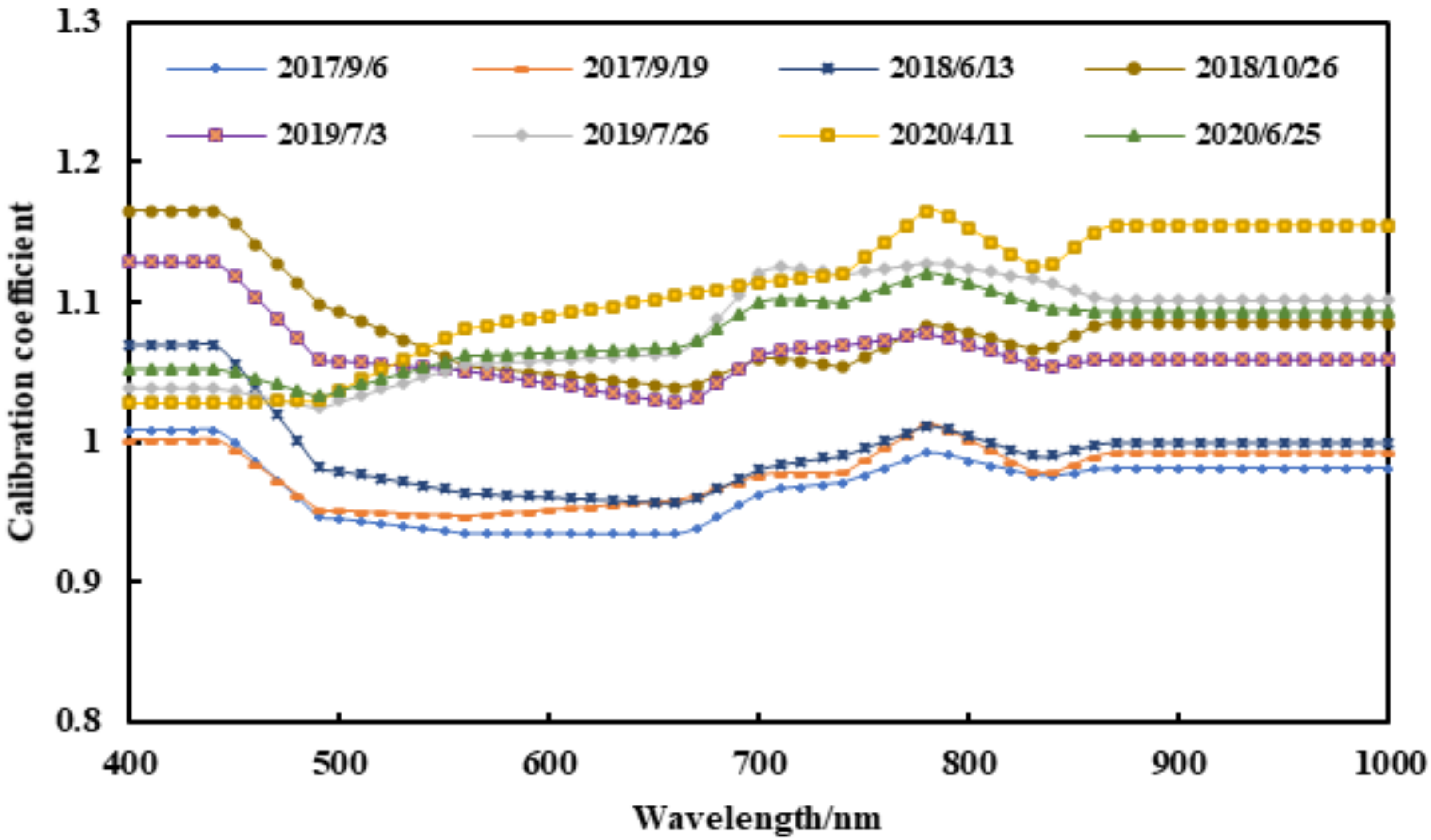
Alignment

Baotou TOA



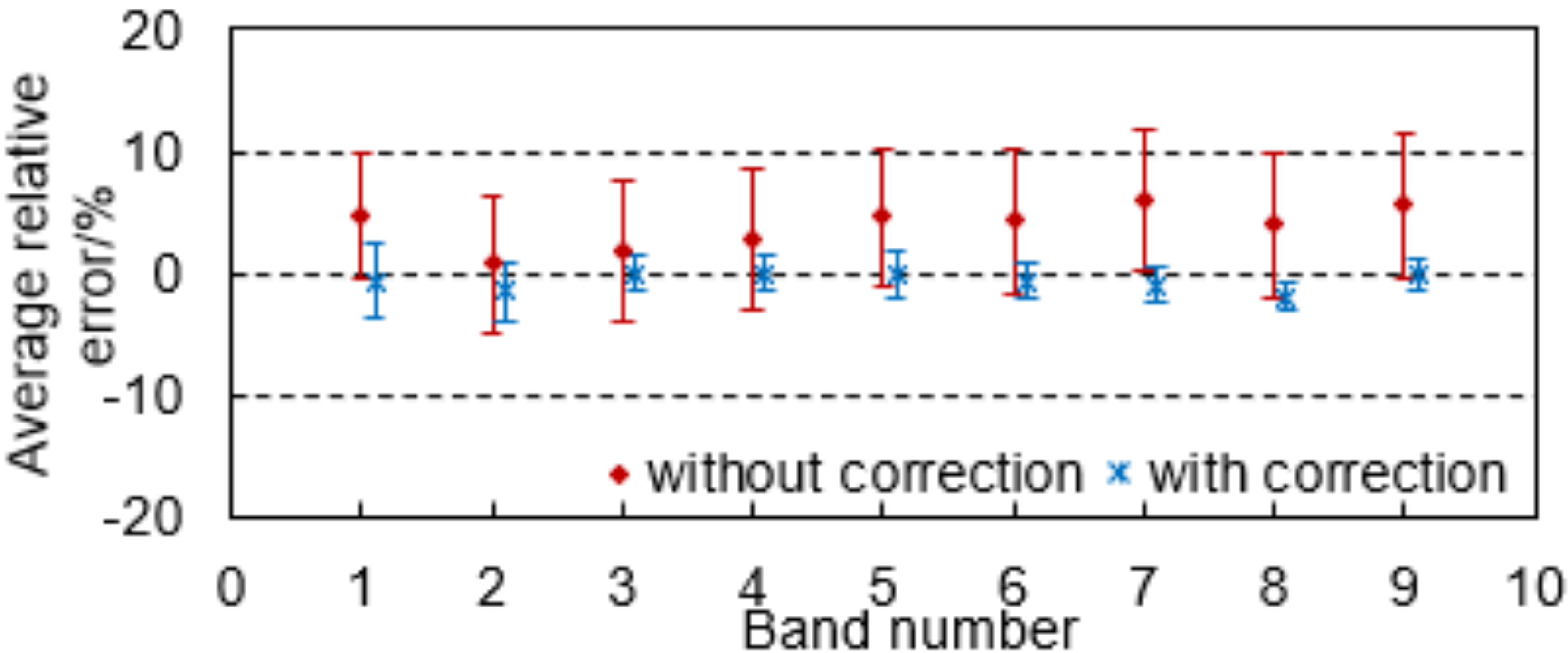
2、 Current research results

Obtaining Calibration Coefficients



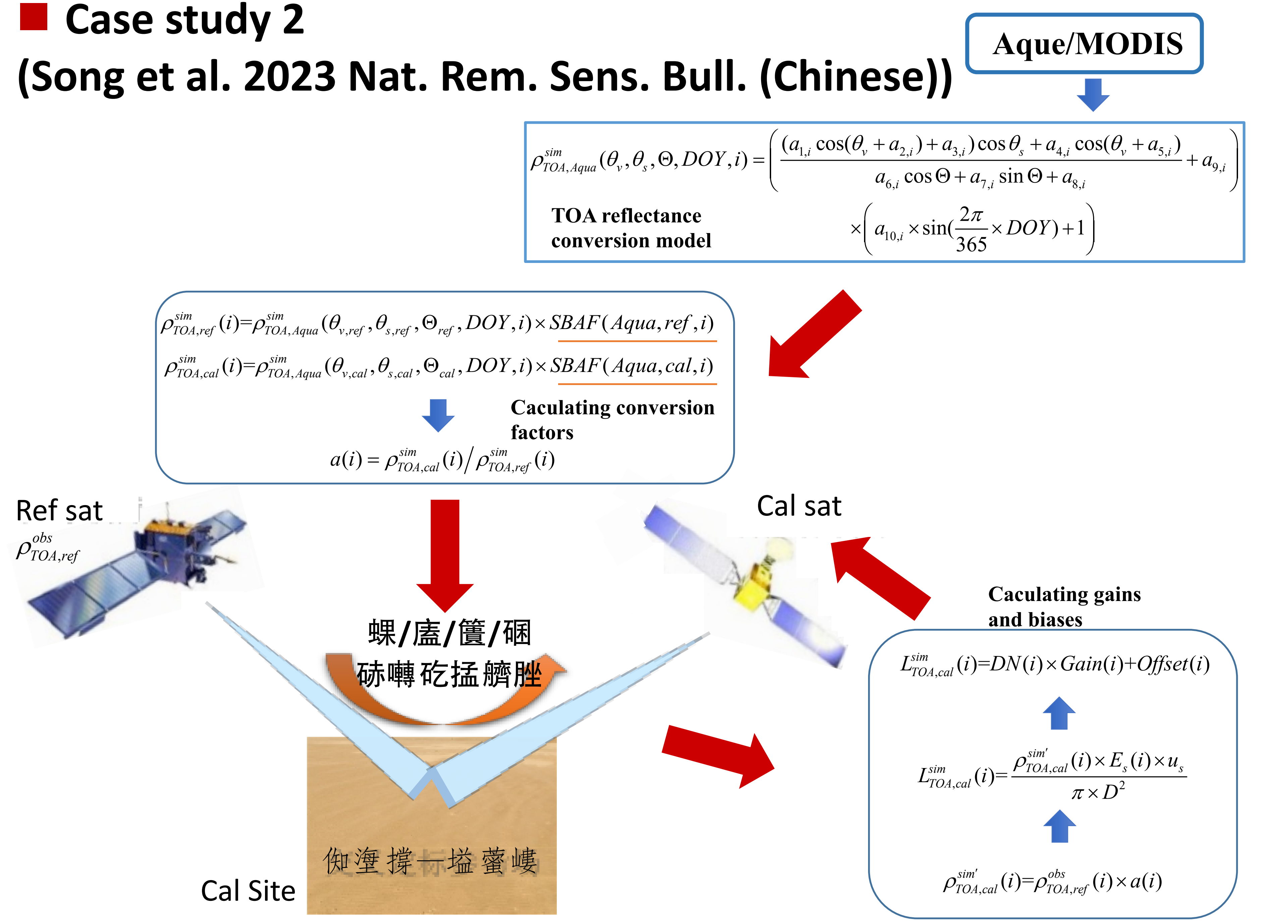
2、Current research results

Applying the Calibration Coefficients



By using this model, the relative difference between TOA reflectance product of Baotou site and the actual TOA reflectance observed by Sentinel 2 can be reduced effectively from 6% to less than 3%. These experiments and results validated the effective of proposed method.

Case study 2
(Song et al. 2023 Nat. Rem. Sens. Bull. (Chinese))



2、 Current research results

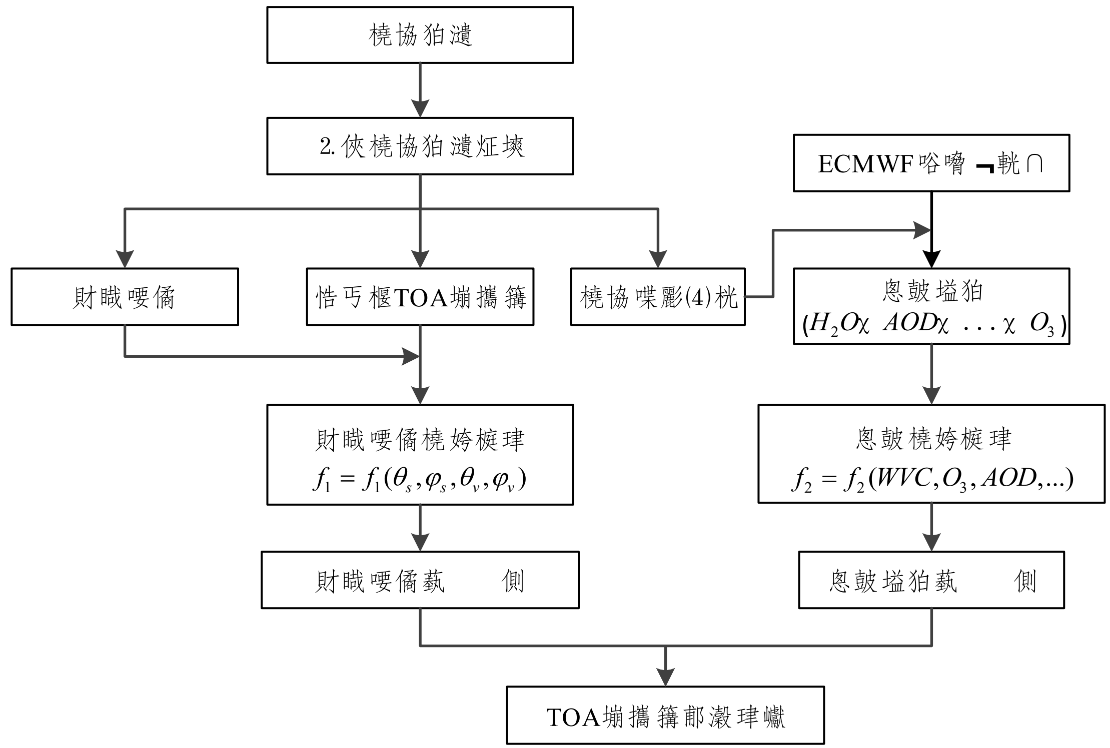
➢ Ideas of modeling

(1) Consider factors such as viewing geometry of solar-target-sensor, surface/atmosphere characteristics, and analyze their influence on TOA reflectance of the reference site.

- ✓ **observing geometry modeling:**

- ✓ **Seasonal variation modeling:**

(2) Develop a TOA reflectance conversion model of reference site for cross-calibration, and analyze constraint conditions of the model.

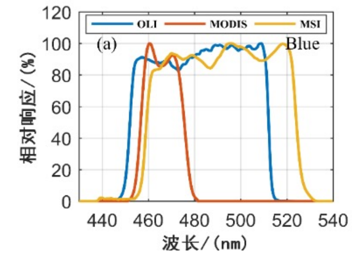


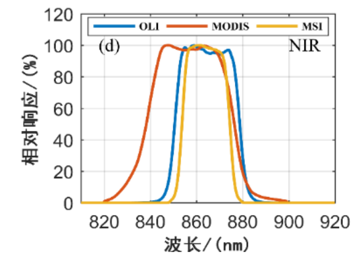
Building the TOA reflectance conversion model

2、 Current research results

✓ **Satellite images:**

Satellite/Sensor	Period [year]	Images [scene]		Function
		Dazaohuo East	Lake Xiaochaidan West	
Aqua/MODIS	2010~2020	1232	1227	modeling
Sentinel-2A/B MSI	2018~2021	31	49	validation
Landsat-8/OLI	2013~2021	37	60	validation



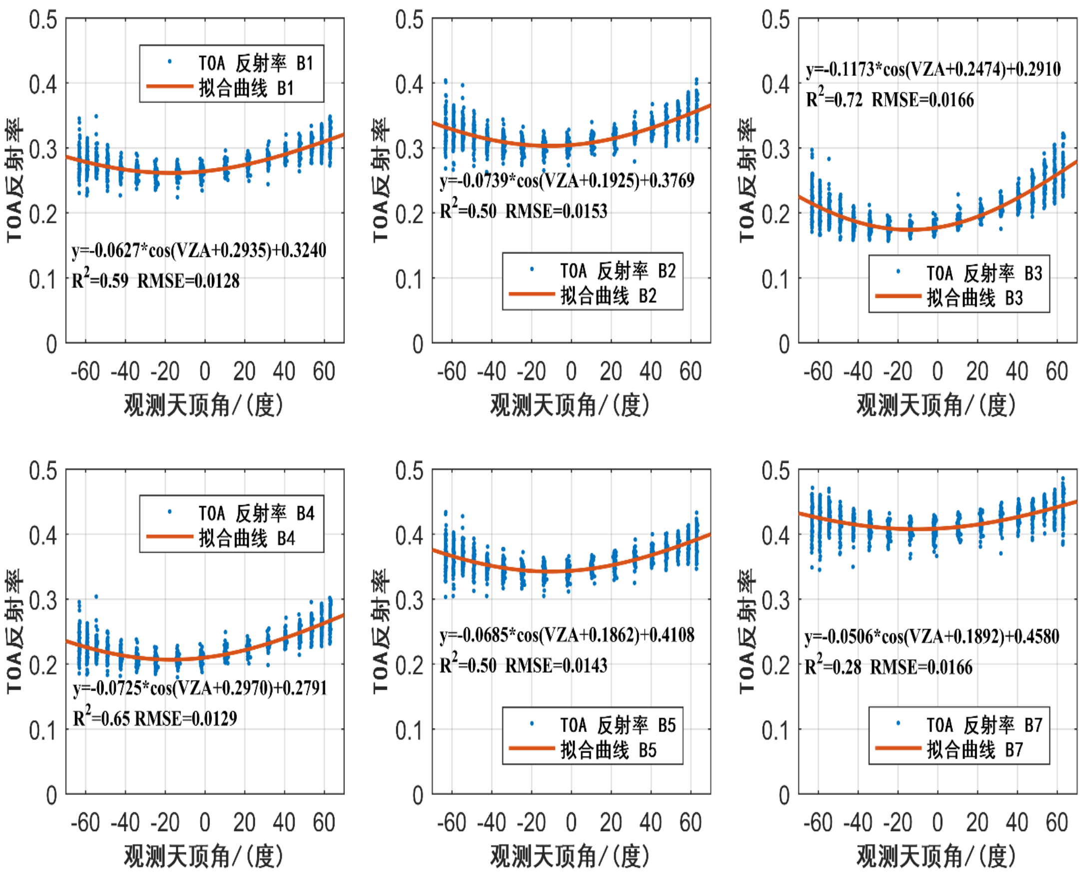


✓ **Reanalysis data:**

Data source	Data description	Period [year]	Function
ECMWF/ERA5	spatial resol: 0.25°×0.25°; temporal resol: 1h	2010~2020	obtain wind speed, precipitation, columnar water vapor, columnar ozone, cloud fraction, etc.
ECMWF/EAC4	spatial resol: 0.75°×0.75°; temporal resol: 3h	2010~2020	obtain AOD

2、 Current research results

✓ **Impact on TOA reflectance by the viewing zenith angle (VZA)**



TOA reflectance changed with viewing zenith angle (cosine fitting)
(Dazaohuo East)

One time item: indicates degree of influence of VZA on TOA reflectance. B7 is minimal.

$$\rho_{TOA} = g(\theta_v) = a_1 \times (\cos\theta_v + a_2) + a_3$$

Constant term 1: reflects TOA reflectance's asymmetry for ipsilateral line-of-sight and bilateral line-of-sight of the satellite and the sun.

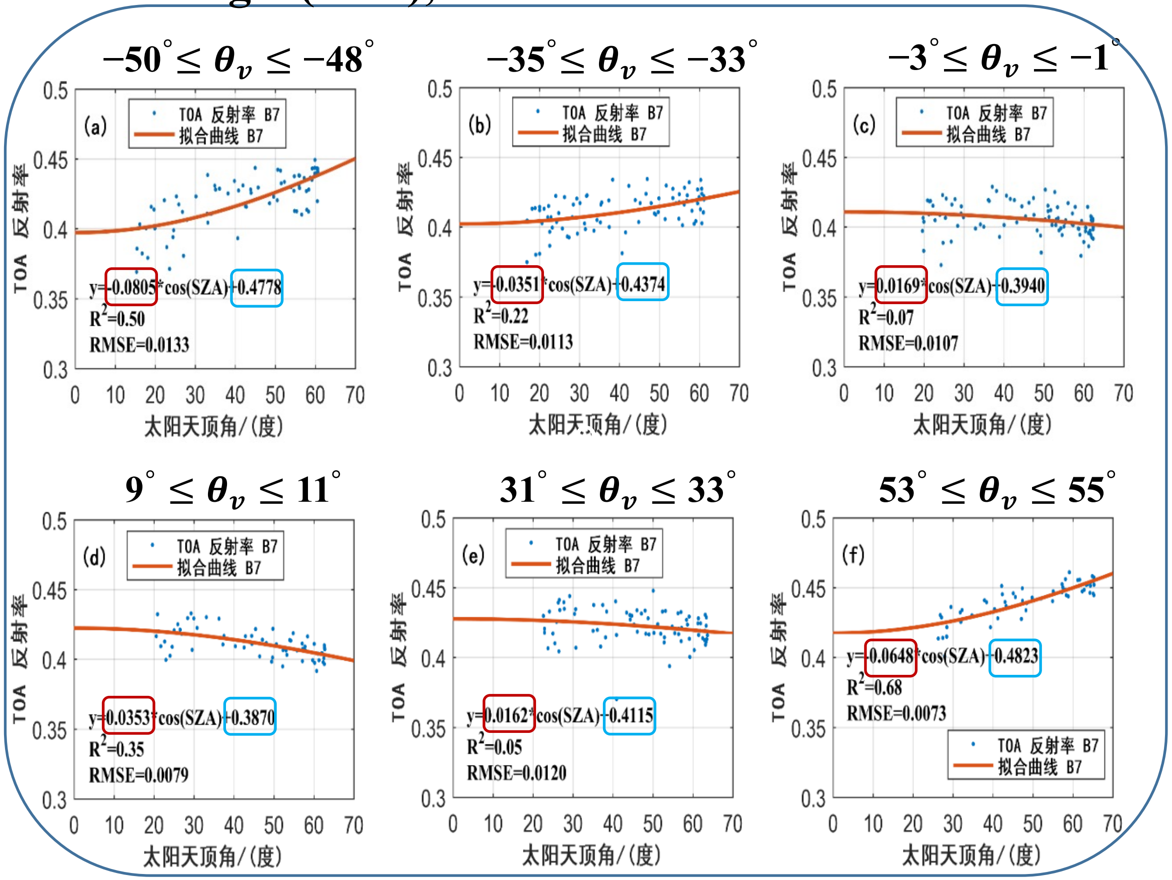
Constant term 2: reflects the mean value of current band's TOA reflectance

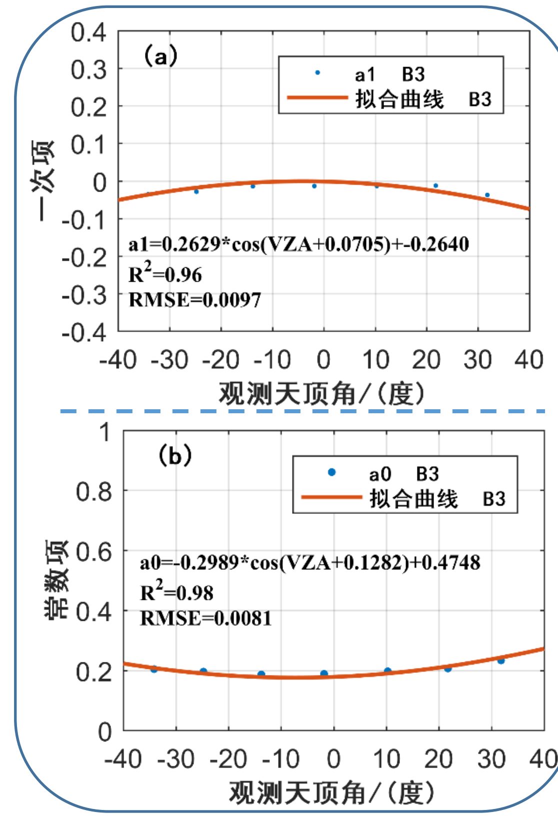
- When the satellite deviates zenith viewing, the TOA reflectance will gradually increase.
- Fitting function: ①quadratic function
- ②cosine function (better result).

2、 Current research results

- ✓ **Impact on TOA reflectance by the solar zenith angle (SZA), under fixed VZA**

$$\rho_{TOA}(\theta_v,\theta_s,i)=b_{1,i}\times\cos\theta_s+b_{0,i}=g_{1,i}(\theta_v)\times\cos(\theta_s)+g_{0,i}(\theta_v)$$



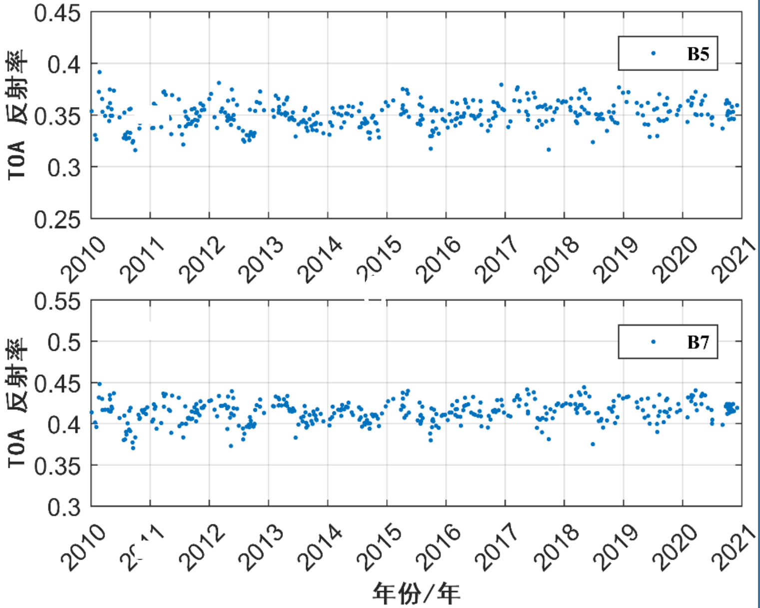


Fitting function: ①linear function of θ_s; ②linear function of $\cos\theta_s$ (when $-35^\circ \le \theta_v \le 35^\circ$, fitting result is better).

2、 Current research results

✓ **TOA reflectance vs. seasonal variation:**

Seasonal variation may lead to seasonal variation of TOA reflectance.

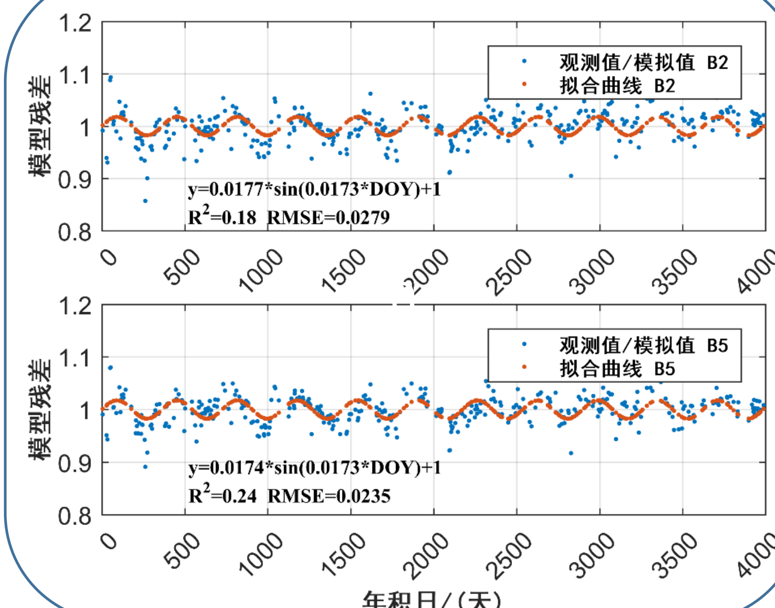


Time-series of TOA reflectance

Fitting function for atmospheric seasonal variation:

$$\frac{\rho_{TOA}^{obs}}{f_1(\theta_v,\theta_s,\Theta,i)} = f_2(DOY,i) = d_{1,i} \times \sin(\frac{2\pi}{d_{2,i}} \times DOY) + 1$$

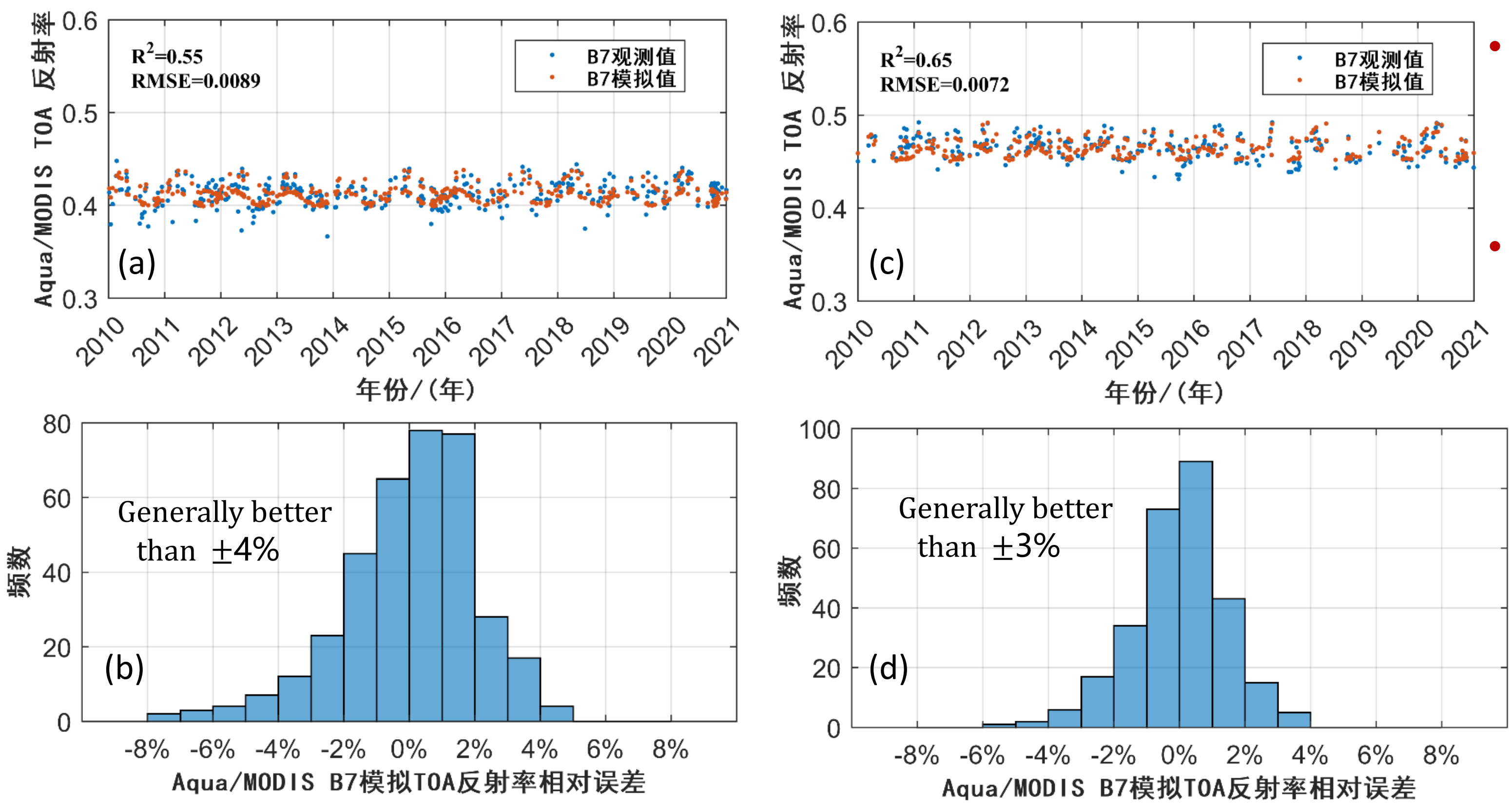
$d_{2,i}$: periods are about 363 days.



2、Current research results

$$\rho_{TOA,Aqua}^{sim}(\theta_v,\theta_s,\Theta,DOY,i)=\left(\frac{(a_{1,i}\cos(\theta_v+a_{2,i})+a_{3,i})\cos\theta_s+a_{4,i}\cos(\theta_v+a_{5,i})}{a_{6,i}\cos\Theta+a_{7,i}\sin\Theta+a_{8,i}}+a_{9,i}\right)\times\left(a_{10,i}\times\sin(\frac{2\pi}{365}\times DOY)+1\right)$$

✓ **Dazaohuo East** ✓ **Lake Xiaochaidan West**



- **No obvious systematic deviation.**
- **Model for Lake Xiaochaidan West is better than model for Dazaohuo East.**

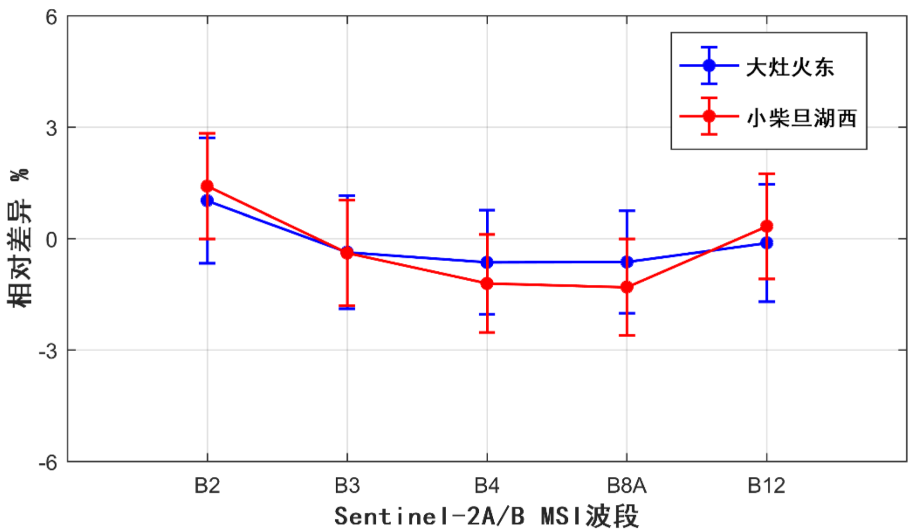
Model simulated values vs. Aqua/MODIS observation values

2、Current research results

✓ **Validation**

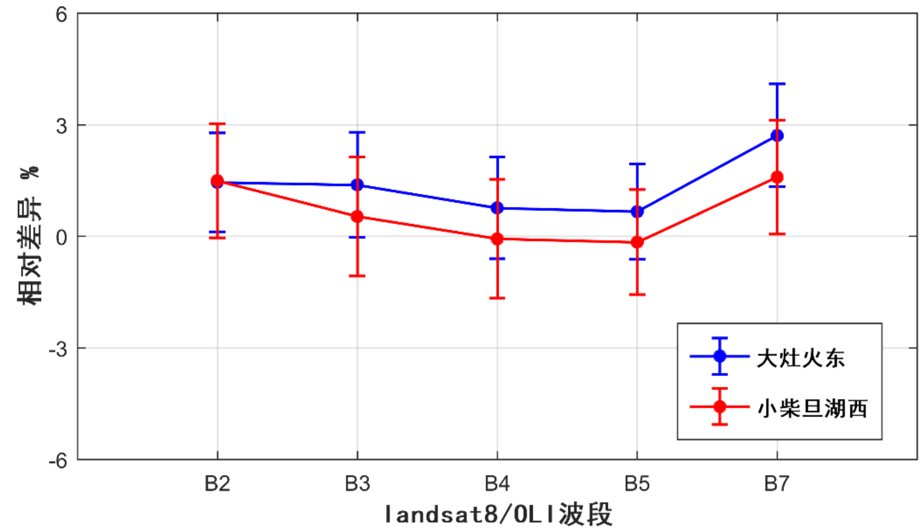
Relative deviation almost <±3% (1 σ, except for B7)

✓ **Sentinel-2A/B MSI**



Error statistics between model simulated values and Sentinel-2A/B MSI observation values, for two reference sites

✓ **Landsat8/OLI**



Error statistics between model simulated values and Landsat-8/OLI observation values, for two reference sites

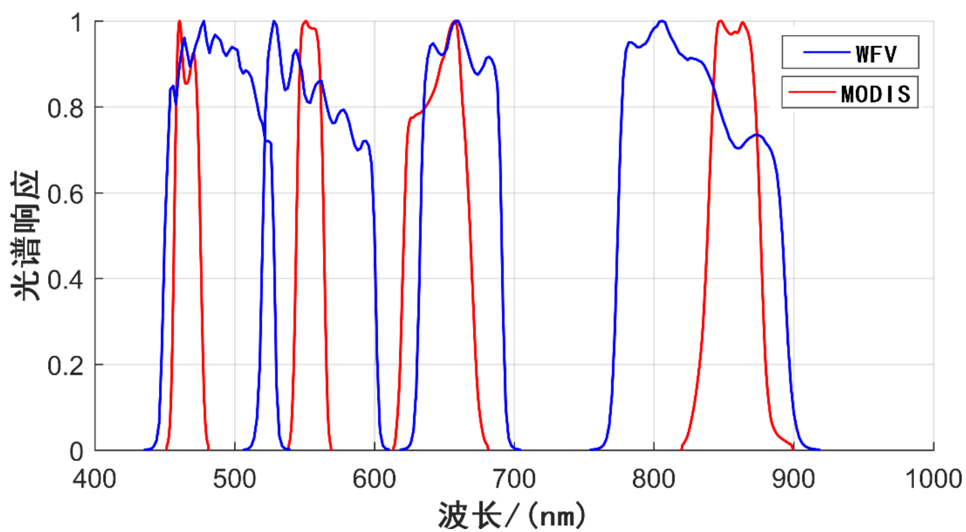
At the two sites, Long-term radiometric consistency can be seen between model simulated values and Sentinel-2A/B MSI (or Landsat-8/OLI) observation values.

2、Current research results

Application

Perform data matching according to overpassing date and time.

Time range: Mar. ~ Nov., in 2019 ~ 2020; Mar. ~ Jun., in 2021.



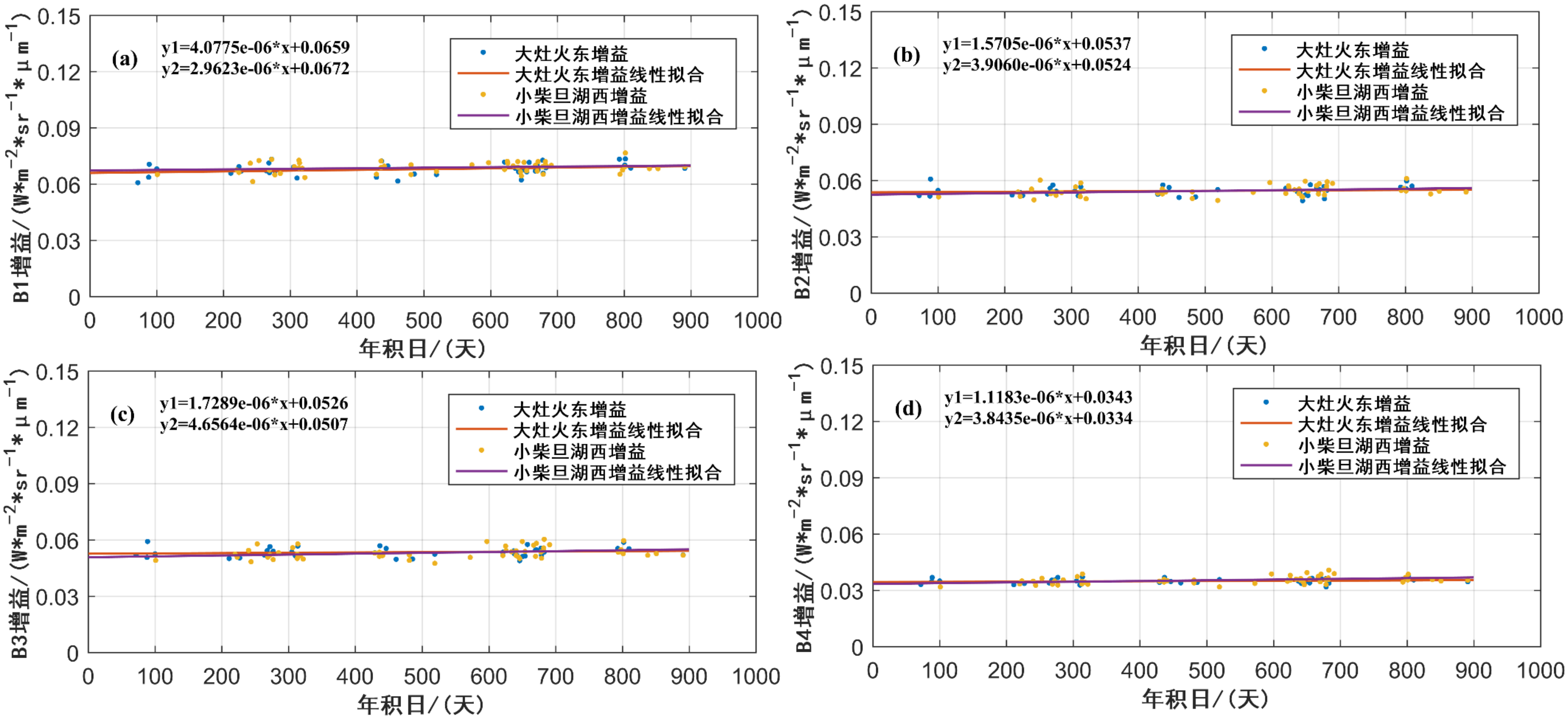
Sensors' SRFs

- ✓ **Reference sensor: Terra/MODIS**
- ✓ **To-be-calibrated sensor: GF6/WFV**

Compared to traditional cross-calibration method, the proposed method can relax observation element difference constraints between reference sensor and to-be-calibrated sensor.

2、 Current research results

✓ **GF6 time series cross-calibration results**



Independent of ground measurement data, 91 times (averaged no less than 2 times per month) of cross-calibration were conducted on GF6/WFV data acquired in 2019 ~ 2021.

2、 Current research results

✓ Compared to official calibration coefficients

- Relative deviations are larger in 2021: 6.11% ~ 10.51% (Dazaohuo East), and 3.66% ~ 9.38% (Lake Xiaochaidan West).
- Relative deviations in 2019 and 2020: within ±5.61% at band B1, B2 and B3; while 6.59% ~ 12.30% at band B4 (NIR).

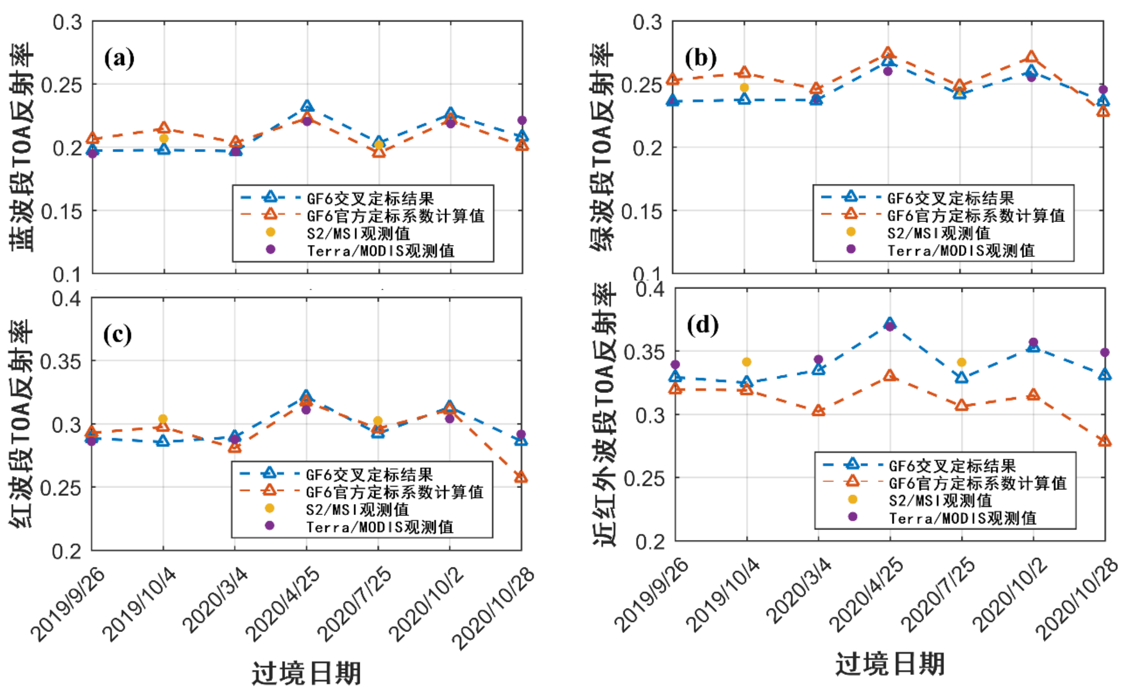
Year	Band	Dazaohuo East /Mean	Lake Xiaochaidan West /Mean	Official gain	Relative deviation	
					Error2	Error3
2019	B1	0.0673	0.0680	0.0705	-4.76%	-3.67%
	B2	0.0542	0.0537	0.0567	-4.57%	-5.61%
	B3	0.0531	0.0522	0.0516	2.88%	1.17%
	B4	0.0346	0.0345	0.0322	7.00%	6.59%
2020	B1	0.0676	0.0691	0.0675	0.12%	2.36%
	B2	0.0540	0.0548	0.0552	-2.20%	-0.81%
	B3	0.0532	0.0536	0.0513	3.66%	4.29%
	B4	0.0348	0.0358	0.0314	9.86%	12.30%
2021	B1	0.0707	0.0692	0.0633	10.51%	8.49%
	B2	0.0567	0.0552	0.0532	6.11%	3.66%
	B3	0.0550	0.0538	0.0508	7.64%	5.56%
	B4	0.0359	0.0359	0.0325	9.37%	9.38%

Calibration coefficients derived by current method have relatively large deviation to official coefficients at the NIR band (B4).

2、Current research results

✓ **Compared to international satellites**

- At Lake Xiaochaidan West site, when time difference < 20min and VZA difference < 15°, a total of 7 scenes of Sentinel-2/MSI and Terra/MODIS images can be found in data matching process.



TOA reflectance comparison against different sensors. (a) blue band, (b) green band, (c) red band, (d) NIR band.段

TOA reflectance derived from the proposed cross-calibration method based on TOA reflectance conversion model, is more closer to TOA reflectance observed by international satellites.

2、 Current research results

Conclusion：

①**Case study 1**

- Develop a method for adjust Baotou site TOA reflectance
  - Can help improve cross calibration accuracy on Baotou site
  - Error reduced from 6% to less than 3%

② **Case study 2**

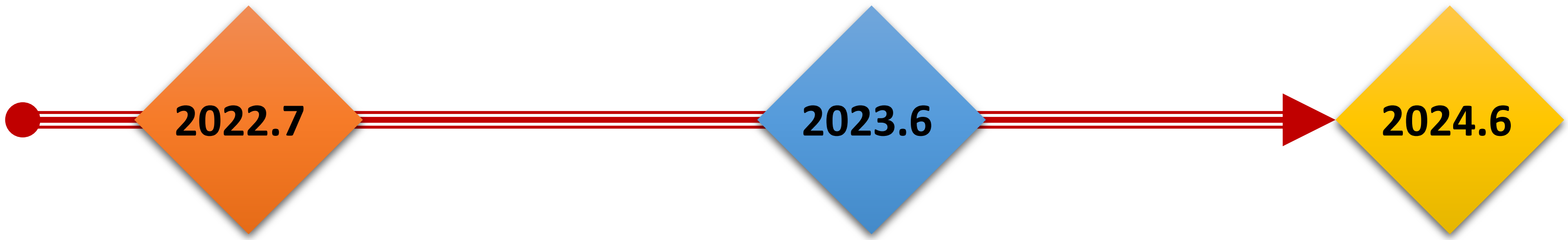
- Develop a level-2 model base on the idea of case study 1
  - Consider more observing geometric and seasonal influence
  - Apply on Chinese satellite GF6, good performance.

2、Current research results

Papers：

- On-Orbit Radiometric Calibration of Hyperspectral Sensors on Board Micro-Nano Satellite Constellation Based on RadCalNet Data, Zhang et al., Remote Sensing, 2022
- An Approach for Evaluating Multisite Radiometry Calibration of Sentinel-2B/MSI Using RadCalNet Sites, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 2021
- An In-Flight Radiometric Calibration Method Considering Adjacency Effects for High-Resolution Optical Sensors Over Artificial Targets, IEEE Transactions on Geoscience and Remote Sensing, 2022
- Cross-calibration of Chinese Gaofen-5 thermal infrared images and its improvement on land surface temperature retrieval, International Journal of Applied Earth Observation and Geoinformation, 2021
- Vicarious Radiometric Calibration of Superview-1 Sensor Using RadCalNet TOA Reflectance Product, IGARSS 2021
- Radiometric Cross-Calibration of GF-4/VNIR Sensor With Landsat8/OLI, Sentinel-2/MSI, and Terra/MODIS for Monitoring Its Degradation, IEEE J-STARS,2020

3、 Work Plan and Schedule



- 4th year (2023.07-2024.06)
  - Further optimization and verification of the radiometric benchmark transfer calibration method based on RadCalNet sites;
  - Carry out China-EU joint application demonstration of radiometric benchmark transfer calibration, and complete the technical report;

Thank you for your attention!

qiushi@aircas.ac.cn