ESA-MOST Dragon Cooperation
中国科技部-欧洲空间局“龙计划”合作

2017 DRAGON 4 SYMPOSIUM
2017年“龙计划”四期学术研讨会

The Achievements on Advanced On-orbit Optical Sensor Calibration and Product Quality Traceability
- Automated Radiometric Calibration

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European PI: Philippe Goryl, ESRIN-ESA, ITALY

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2017年6月26-30日，丹麦 哥本哈根

1. Background & Motivation

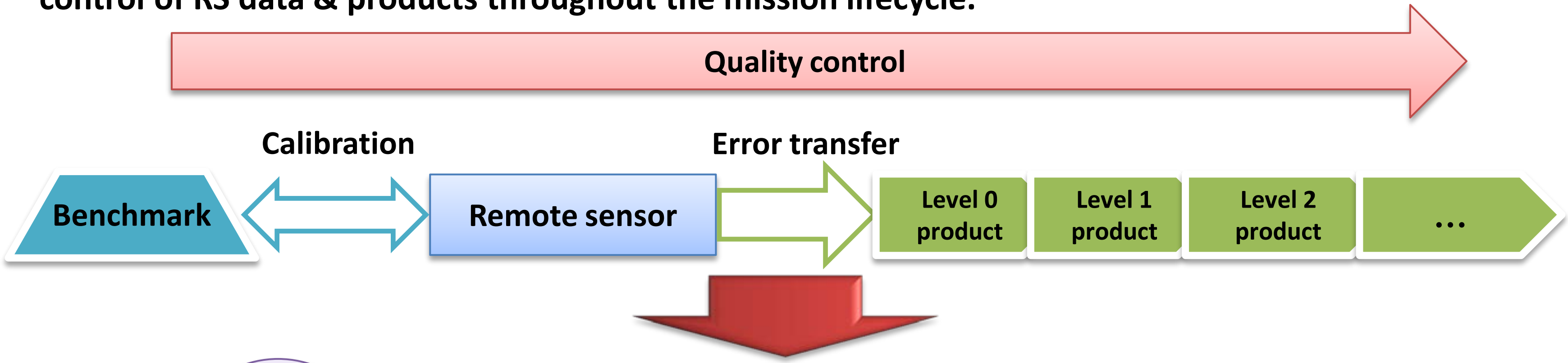
Project ID 32426: Calibration and Data Quality Assurance for Quantitative Remote Sensing

European Leader Investigator	Chinese Leader Investigator
Prof. Philippe Goryl	Prof. Chuan-rong Li
ESRIN/ESA, ITALY	AOE/CAS, CHINA

Topic Nr.	PIs	Title
32426_1	Philippe Goryl, Lingling Ma	Advanced On-orbit Optical Sensor Calibration and Product Quality Traceability
32426_2	Ralf Bennartz, Xiaolong Dong	Microwave RS sensor calibration and product generation (MIRSS-CAP)
32426_3	Michel Van Roozendael, Cheng Liu	MAXDOAS Fiducial Reference Measurements in Eastern China (MAXFRM)
32426_4	Bart Dils, Prof. Pucai Wang	Joint Optimization of Chinese ground-based FTIR Reference Measurements (JOCFRM)

1. Background & Motivation

Calibration: Relate remote sensor to the reference benchmark through a continuous traceability chain, determine the parameters needed to characterize sensor performances, in order to promote quality control of RS data & products throughout the mission lifecycle.



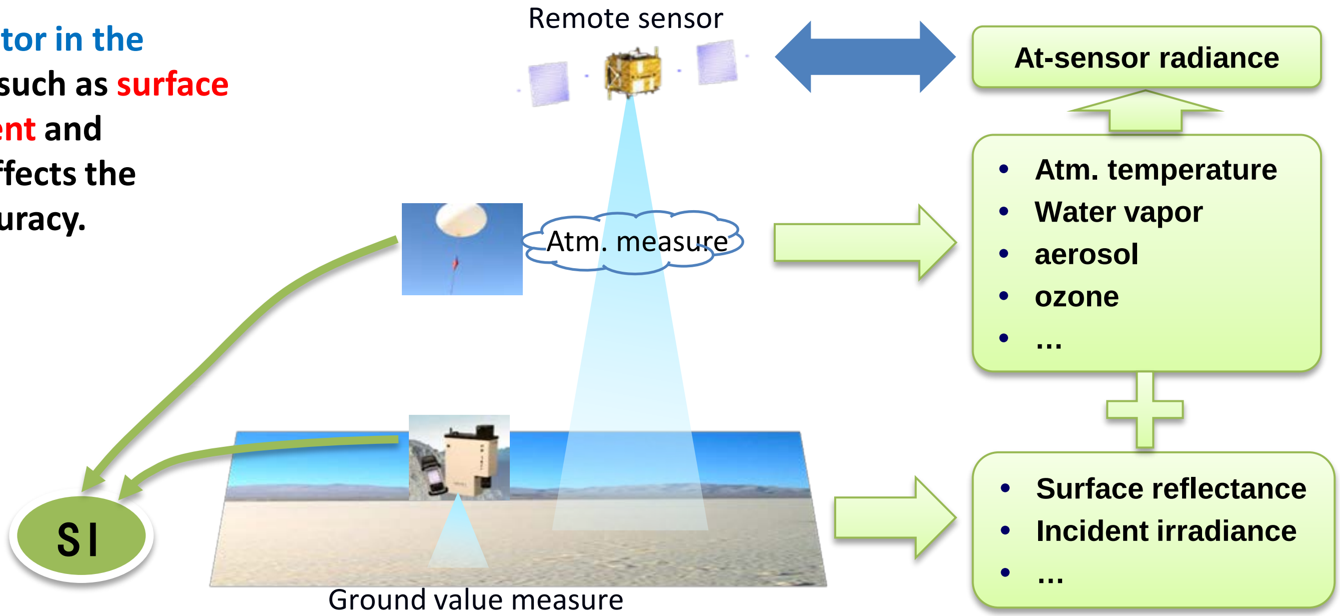
Challenges of Calibration

- Quantitative information products → Calibration accuracy
- High resolution trend → Temporal applicability
- Global data sharing & services → Benchmark consistency

1. Background & Motivation

Ground-based Radiometric Calibration, realized by the radiative transfer simulation based on ground target and atmospheric parameter measurement, is the effective way for the on-orbit performance evaluation and product validation.

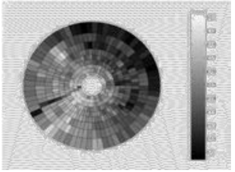
The uncertainty of each factor in the benchmark transfer chain, such as surface target, measuring instrument and radiative transfer model, affects the consequent calibration accuracy.



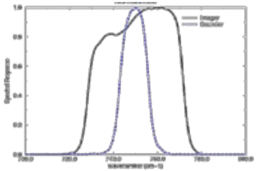
1. Background & Motivation

Calibration accuracy

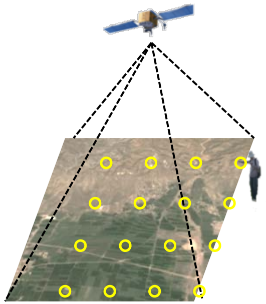
Influenced by multi-source uncertainties due to different observing scales, variant atmospheric environment, etc., current radiometric calibration accuracy is usually hard to meet the requirements of quantitative RS applications.



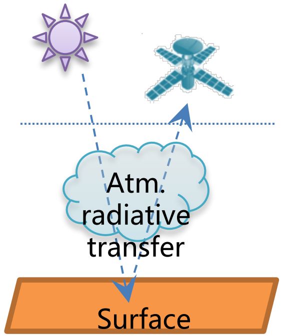
Surface anisotropy



Spectral discrepancy between sensors



Spatial scale mismatching



The difficulties:

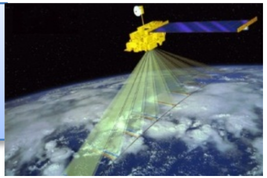
- How to establish an unbroken chain traced to SI?
- How to determine and assign uncertainties for each factor?
- How to reduce measurement errors on each factor such as surface targets, measuring instruments and transfer model.

1. Background & Motivation

Temporal applicability

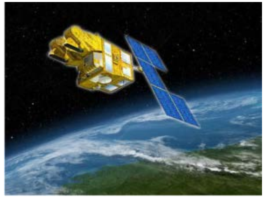
Considering suitable geographical region and weather condition, especially the longer revisit period induced by incresingly high resolution observing capability, the ground-based calibration effort is usually hard to describe the variation of sensors.

Revisit period



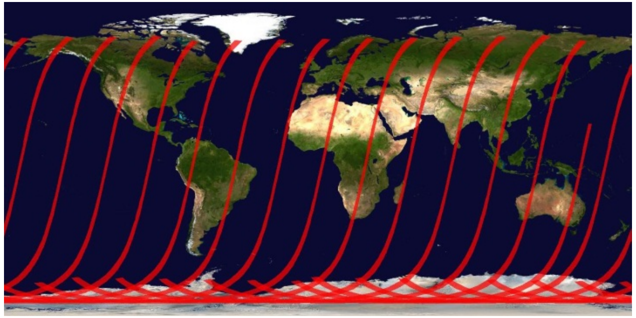
Terra/MODIS
Resolution: 250~1000m
Swath: 2330km
Revisit: 1 day

Landsat-8/OLI
Resolution: 30m
Swath: 185km
Revisit: 16 days

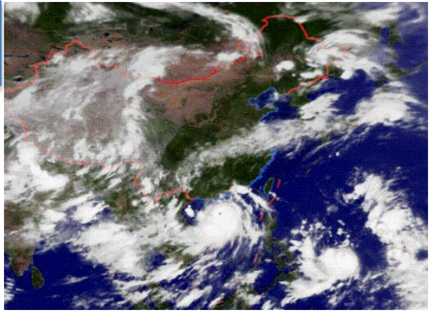


SPOT-5
Resolution: 10m
Swath: 60km
Revisit: 26 days

ZY-3
Resolution: 6m
Swath: 51km
Revisit: 59 days



Cloud

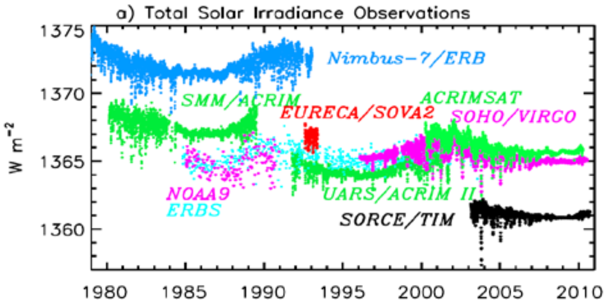


Usually 60%-70% range of the Earth is covered by cloud

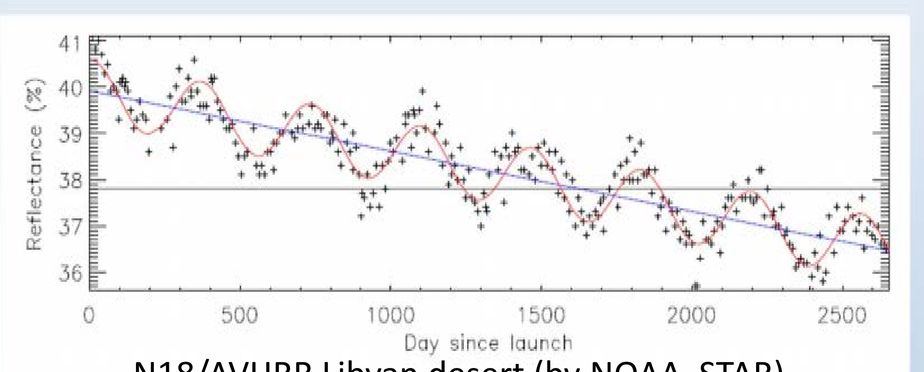
1. Background & Motivation

Benchmark Consistency

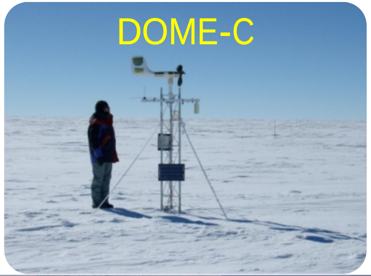
1. **The products derived from different sensors are not consistent.**
2. **Even for the same payload, the measurement results from different sites or from the same site but different times are different, lacking of repeatability, due to the differences in instrument, method, etc.**



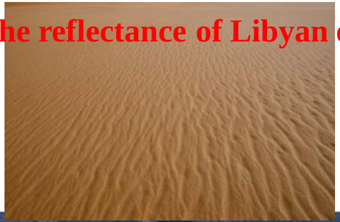
Plot reproduced from Kopp and Lean, 2011



N18/AVHRR Libyan desert (by NOAA, STAR)



The reflectance of Libyan desert is very stable

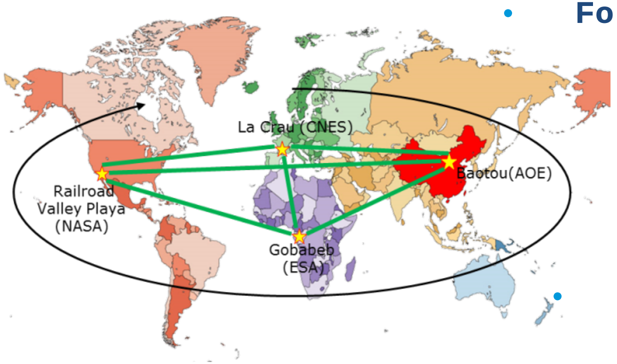


ETM+

1. Background & Motivation

To build a prototype of "global calibration" traceable to SI, CEOS/WGCV/IVOS WG agreed to set up the RadCalNet (Radiometric Calibration Network of Automated Instruments) in 2014.

1. **Large dynamic range, global-distributed reference sites can reduce the uncertainty of single site calibration;**
2. **Automatic and traceable radiometric calibration technology, instead of the traditional synchronous field measurement campaign, ensures the temporal applicability of ground-based calibration.**



- **Four demonstration sites:**
  - ✓ **Baotou site (China, AOE)**
  - ✓ **La Crau site (France, CNES)**
  - ✓ **Railroad Valley Playa site (USA, NASA)**
  - ✓ **Gobabeb (Namibia, ESA)**
- **NPL (UK) provides support in harmonization, traceability, instrument calibration and QA4EO**

1. Background & Motivation

SP1. Advanced On-orbit Optical Sensor Calibration and Product Quality Traceability

Objectives

- To explore new technology and algorithms for high accuracy on-orbit radiometric calibration and validation which can be used to Chinese and European remote sensing satellites. The following new approaches will be focused:
  - Networked ground automated radiometric calibration technique.
  - Consistent transfer calibration based on space-borne radiometric benchmark.
  - Step-validation methods based on airborne standard hyperspectral imagers.
  - Quantitative RS product quality index set and RS standardization.
- To form long-term joint-experiment mechanism with EU and Sino members.
- To train youth Cal&Val scientists via workshops, training programs, co-supervision and exchange.

1. Background & Motivation

SP1. Advanced On-orbit Optical Sensor Calibration and Product Quality Traceability

Team composition

RS data processing and application experts

Operational management institution for Chinese satellites

CRESDA, CMA

Sensor R&D experts

R&D institutes to design Vis-SWIR/TIR/ hyperspectral cameras used in remote sensing in China

AIOFM-CAS, CIOMP-CAS, SITP-CAS

Metering experts

NPL, NIM

UK and China's national metrology institute

Focus on the satellite data processing, calibration

ESRIN-ESA, ESTEC-ESA

AOE-CAS

Rich experience in optical sensor vicarious calibration, and is managing and maintaining the Baotou High Resolution Cal&Val Site which has been enrolled in the RadCalNET

Cal&Val experts

1. Background & Motivation

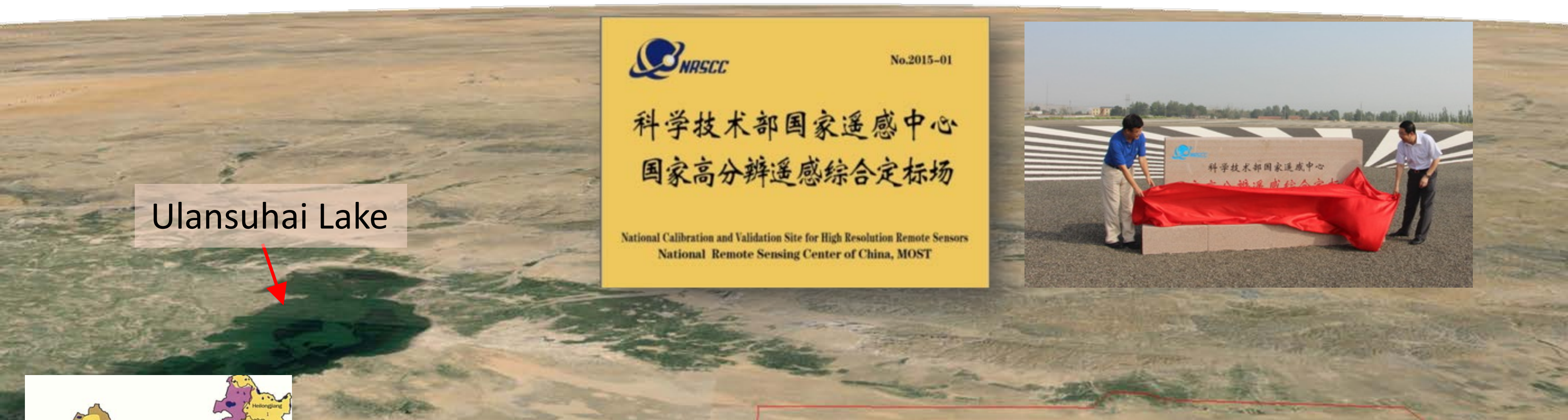
Since the kick-off of the project, the focus is on cooperative research on **Networked ground automated radiometric calibration technique** based on RadCalNet activities and permanent targets over Baotou site in China. It mainly includes:

- **Development of automated radiometric calibration system and its operations.**
- **Automated radiometric calibration demonstration for Chinese and European satellites.**
- **The uncertainty analysis on the standard radiometric calibration product.**
- **Communication and training.**

2. Development of automated radiometric calibration system

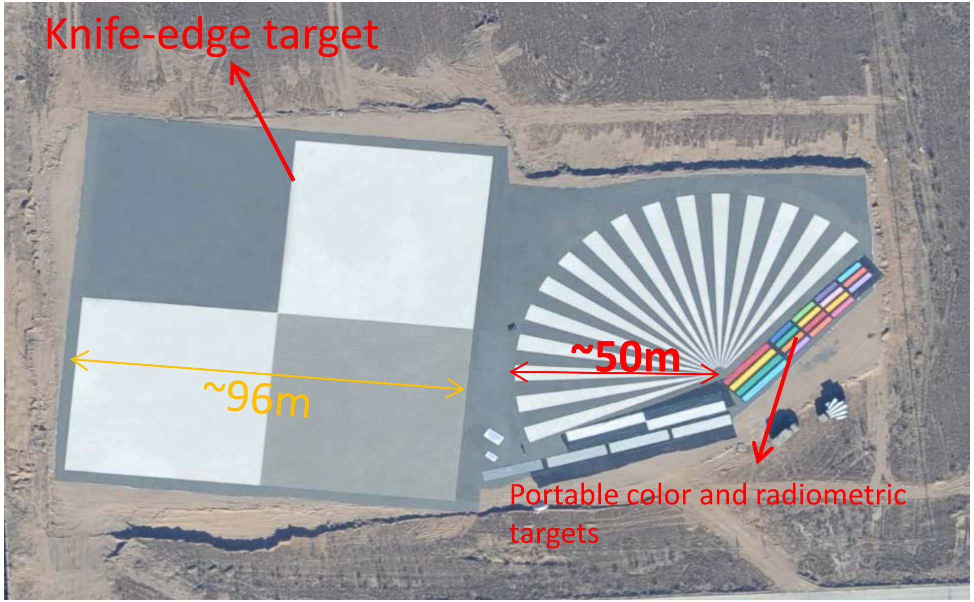
Baotou site

- Located in Inner Mongolia, China, 50km away from the Baotou city.
- A flat area of approximately 300km^2, about 1270m above sea level.
- Features a cold semi-arid climate with about 300 fine days per year.
- It is designated as "**National calibration and validation site for high resolution remote sensors**"by NRSCC,MOST, and is also one of the demonstration sites of the **RadCalNet**.



2. Development of automated radiometric calibration system

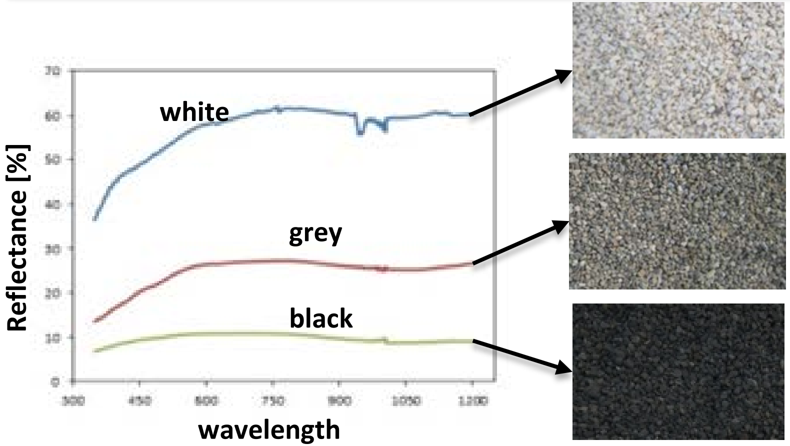
Artificial permanent targets



Aerial image of the artificial permanent targets

Dedicated to high-accuracy and high-stable radiometric calibration:

- **High-stable**: made of natural gravels
- **Wide-range**: three grey-scale
- **Well-uniform**: heterogeneity <3%



Gravel (size<1.5cm)

2. Development of automated radiometric calibration system

Natural Targets

For the Cal/Val of medium-resolution spaceborne sensors, large-size natural targets were developed and maintained inside the Baotou site, e.g., desert (300m×300m), maize field (300m×300m), sunflower field (300m×300m).


Sunflower


Potato


Alfalfa


Grassland


Maize


desert


Clay soil


Wulansuhai Lake

2. Development of automated radiometric calibration system

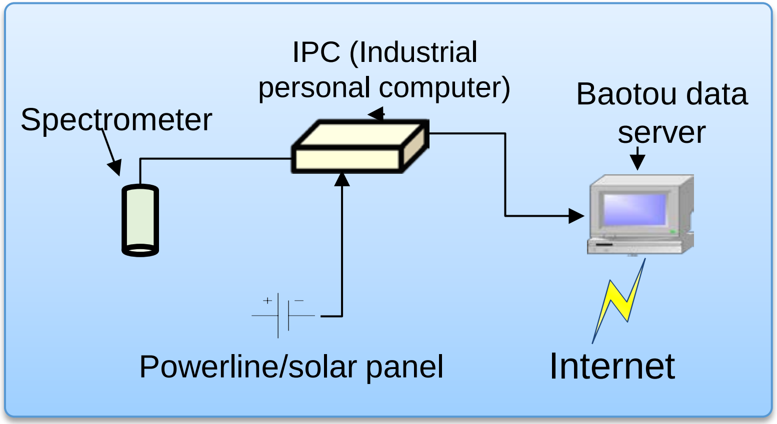
Automated surface spectral radiance measurement system

■ **Four automated surface spectral radiance measurement system has been developed and installed over three permanent artificial targets and desert with different reflectance.**

- *Cover a spectrum range from 380 to 1080 nm with spectral resolution of 2 nm.*
- *In the operational phase from 2016.*
- *Measurements can be transferred to Beijing via internet and GPRS network.*

Black target

Gray target

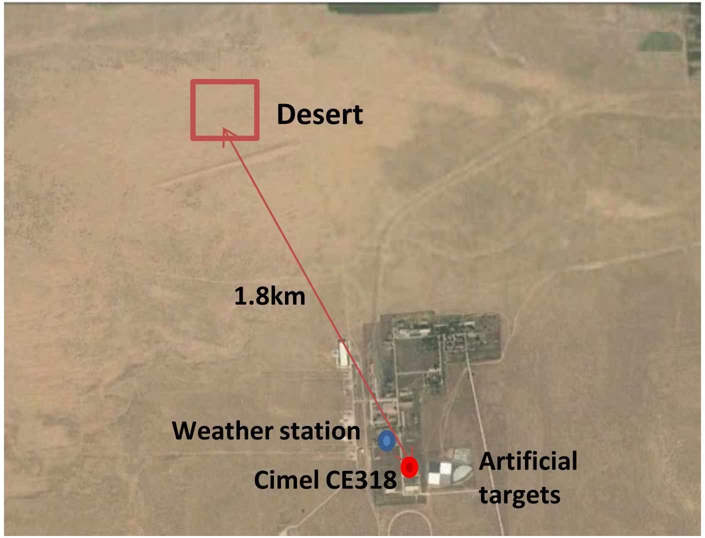


White target

Desert target

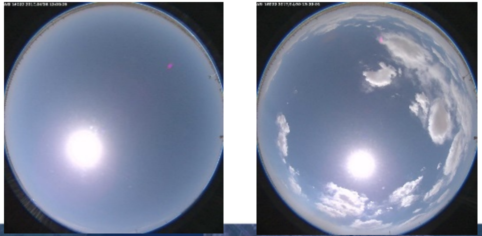
2. Development of automated radiometric calibration system

Automated atmospheric and meteorological measurement system



All-sky imager

Sun-photometer



Cloud amount observation

Weather station

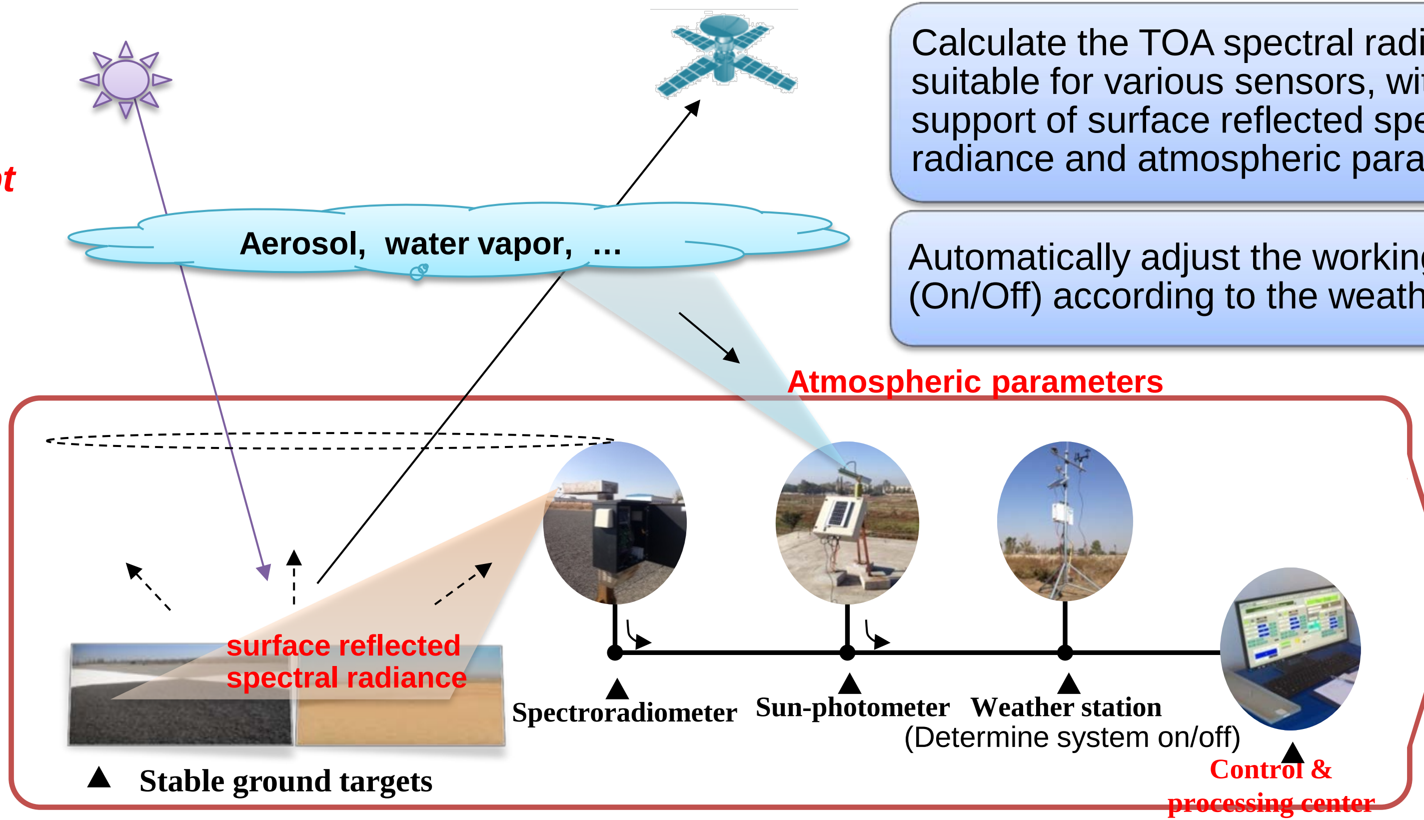
- Aerosol optical thickness
- water vapor content
- aerosol angstrom coefficient,
- humidity
- Pressure
- Temperature
- cloud amount
- …

2. Development of automated radiometric calibration system

Calculate the TOA spectral radiance suitable for various sensors, with the support of surface reflected spectral radiance and atmospheric parameters;

Automatically adjust the working status (On/Off) according to the weather condition.

Concept



Sensor-independent TOA radiance/ reflectance

2. Development of automated radiometric calibration system

Atmospheric parameters including:
Aerosol optical thickness;
Columnar water vapor;
Absorption and asymmetry coefficients;
Phase function; ...

Automated observing system

Atmospheric radiative transfer model

Total radiance @ ground (direct & sky radiance)

Ground reflected radiance

Background reflectance

Targets Reflectance

Atmospheric radiative transfer model

TOA spectral radiance

SRF

Calibration

RadCalNet has drawn up the normalized production process for standard radiometric calibration products.

For the long-term running, the reference panel is cancelled, the key point of automated data processing is to determine the targets BOA reflectance from reflected radiance and atmospheric parameters measurement.

$$\boxed{\rho} = \frac{\pi \boxed{L_g}}{\boxed{E_{solar}^{direct}} + \boxed{E_{sky}^{diffuse} + E_{sky}^{scat}}}$$

At-ground reflected radiance

Direct radiance

Sky radiance

2. Development of automated radiometric calibration system

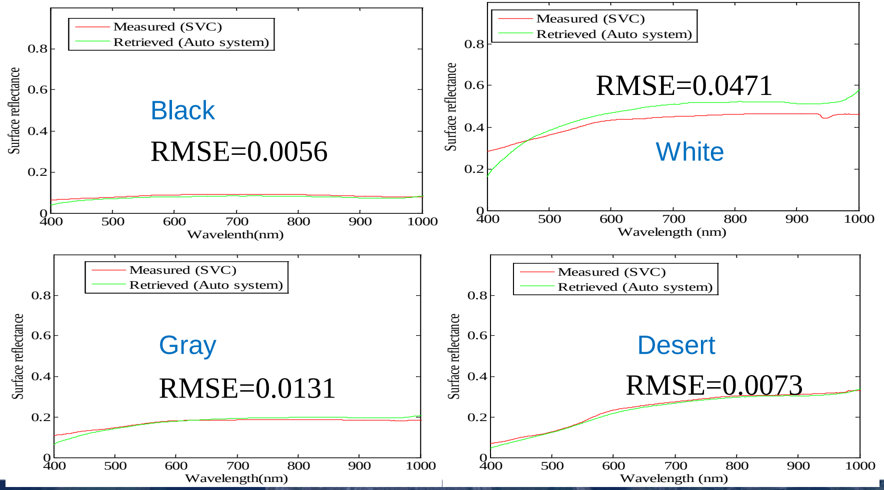
Generation of BOA reflectance product in Baotou Site

- ✓ **The surface reflectance is retrieved from the observed reflected radiance and the measured atmospheric parameters, with the support of atmospheric radiative transfer model (MODTRAN);**
- ✓ **Automated system only observes surface at fixed point. Because of the heterogeneity of the target, the reflectance should be corrected according to the historical surface measurement.**

***Red lines**: averaged reflectance spectrum over whole target measured by SVC*

***Green lines**: fixed point reflectance spectrum calculated with the automated measurement system*

Fixed point (green curves) V.S. Area average (red curves)

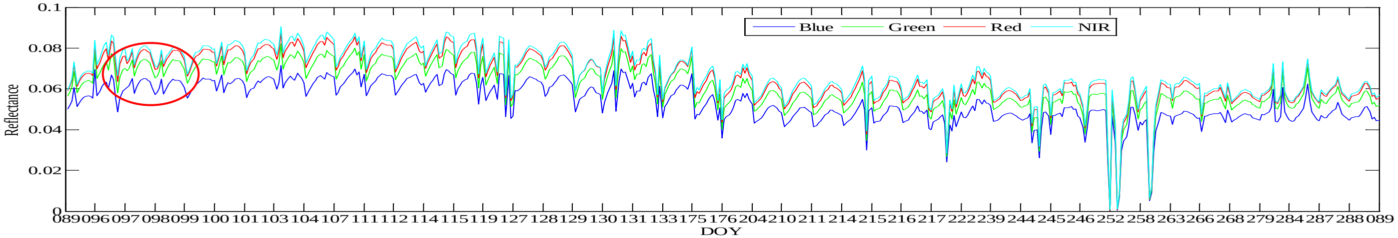


The calculated surface reflectance has been compared with the in-situ measurements. Results show good agreement, except for the white target, which is probably caused by the larger heterogeneity of the target.

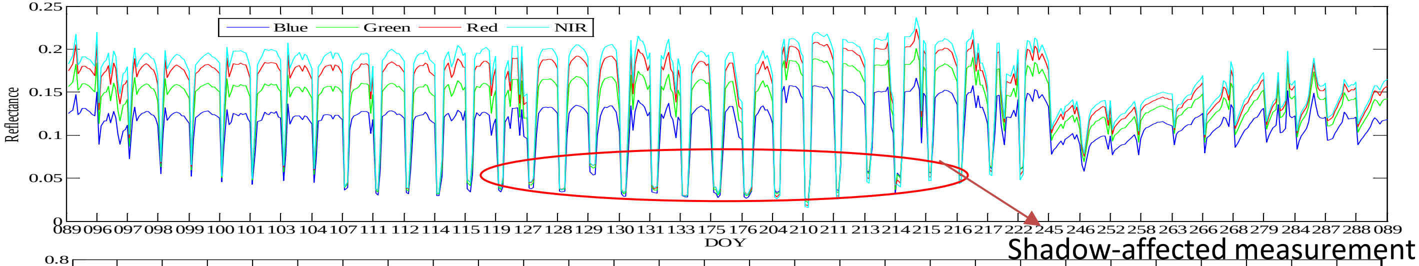
2. Development of automated radiometric calibration system

Demonstration of series surface reflectance (9:00-15:00 local time, one value/half an hour).

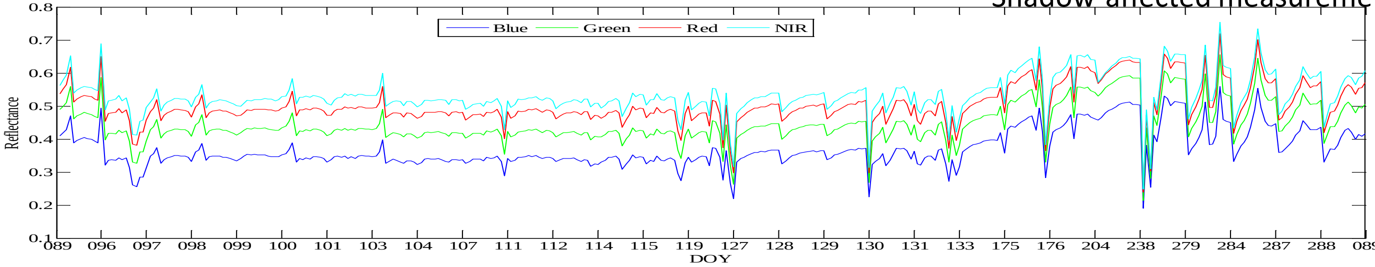
Black



Gray

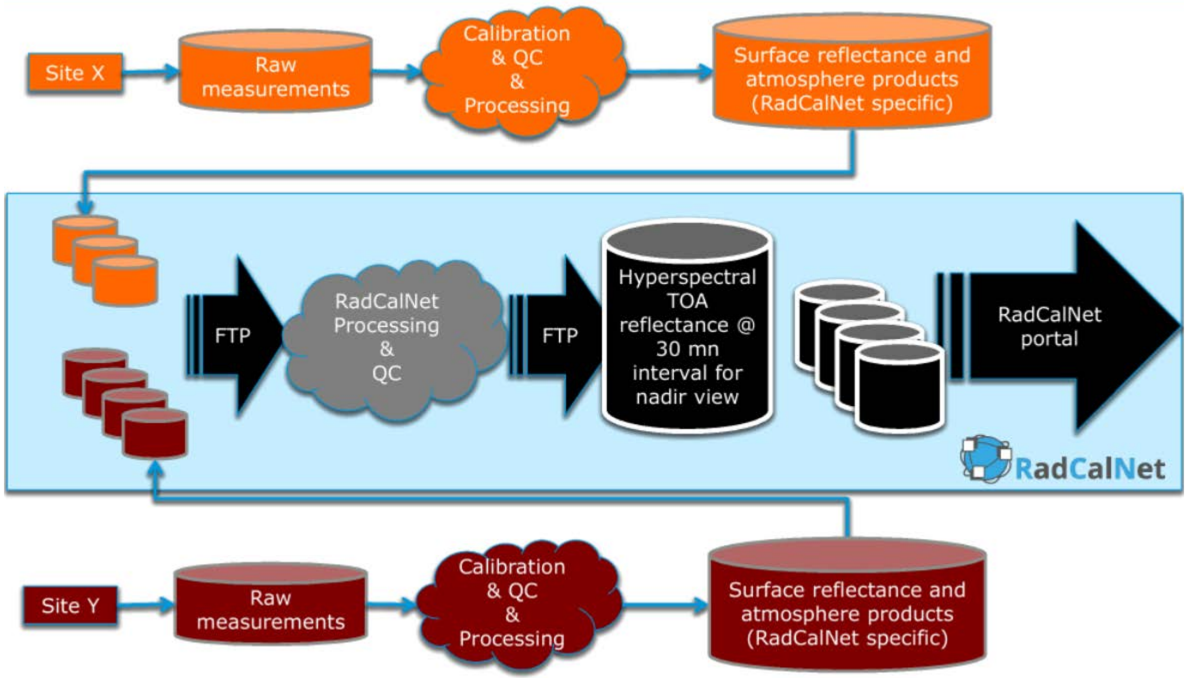


White



In normal days, the surface reflectance changed due to the BRDF effect, since the solar zenith angle and azimuth angle are changing over time.

2. Development of automated radiometric calibration system



The flowchart of the standard data process of the RadCalNet

Sensor-independent TOA reflectance and associated uncertainties at 10 nm intervals and 30 minute intervals from 9:00 to 15:00 (local time for each site) .

2. Development of automated radiometric calibration system

RadCalNet CEOS Committee on Earth Observation Satellites Sign In

RadCalNet Data Center https://www.radcalnet.org/

Welcome to the Radiometric Calibration Network portal

RadCalNet is a CEOS WGCV initiative to provide satellite operators with SI-traceable Top-of-Atmosphere (TOA) spectrally-resolved reflectances to aid in the post-launch radiometric calibration and validation of optical imaging sensors from a coordinated network of instrumented land-based test sites. The free and open access service provides a continuously updated archive of TOA reflectances and associated uncertainties at 10 nm intervals spanning the spectral range 380 nm to 2500 nm at 30 minute intervals* from each of its member sites together with some tools to aid in its use. Each individual site is well characterised and equipped with ground monitoring instrumentation to provide continuous measurements of both surface reflectance and local environmental/atmospheric conditions to facilitate the derivation of TOA reflectance values. Each member site takes responsibility for its own quality assurance but is subject to peer review and rigorous comparison to ensure site-to-site consistency and SI traceability. TOA reflectances provided on this portal are processed from the individual sites using a common method through a central processing system.

*Only data meeting RadCalNet defined minimum QA will be made available, and each data set is associated with its own specific uncertainty budget.

- **To ensure site-to-site consistency and SI traceability**

- **To provide the opportunities to the satellite management organization which have no conditions to organize field calibration campaign**

The characteristics of each individual RadCalNet site are provided in the portal together with an indication of each site's suitability for different sensor types. Access to the portal and its content is open to anyone following registration. In using the service we ask that you adhere to our data policy RadCalNet_Data_Policy_v1.1.pdf and provide us with feedback to help us improve the service, which we intend to extend and evolve. For more specialist information tailored to a particular satellite or observation conditions users are requested to individual site owners directly. We welcome new sites to and encourage potential site owners to consider joining this initiative (Radcalnet_Membership_criteria_v20160217.pdf).

Sign In

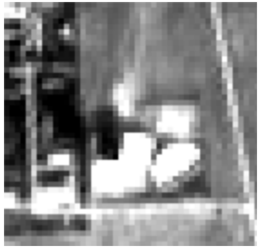
Contact Admin

3. Demonstration for Chinese and European satellites

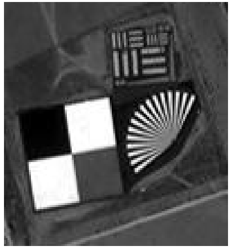
List of Chinese and European satellites (GSD≤10m)

Satellite	2016	2017
Sentinel-2a	3/30, 4/29, 5/29, 7/28, 8/7, 8/20, 8/27, 9/16, 11/5, 11/15, 12/15, 12/18	4/14, 4/24, 5/7, 5/24, 6/3
GF-1	04/23,06/07,08/20,8/24,8/28,11/14,11/30	04/23
GF-2	04/22	03/28
ZY3	04/20,8/21,8/26	
ZY3-02	07/20	05/06,05/11,05/16
ZY-02C	04/16,04/19,04/22,04/25,04/28,05/12,06/07,12/24	04/13
CBERS-4	06/07	

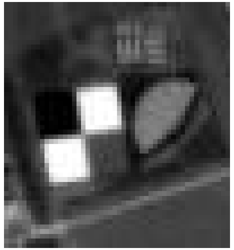
From the end of February 2016, there are 44 matchups for Sentinel-2a, ZY-3, ZY-02C, GF-1, GF-2 and CBERS-4 satellites.



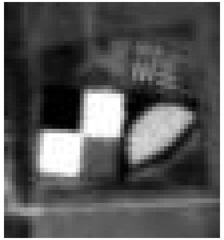
Sentinel-2a (MUX: 10m)
29 April, 2016



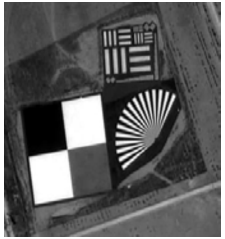
GF-1 (Pan:2m / MUX:8m)
7 June, 2016



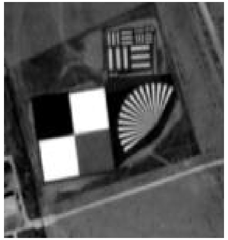
ZY-02C (Pan:5m / MUX:10m)
7 June, 2016



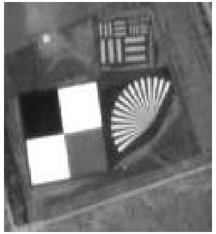
CBERS-4 (Pan:5m / MUX:10m)
7 June, 2016



GF-2 (Pan:1m / MUX:4m)
22 April, 2016



ZY3 (Pan:2.1m / MUX:6m)
20 April, 2016

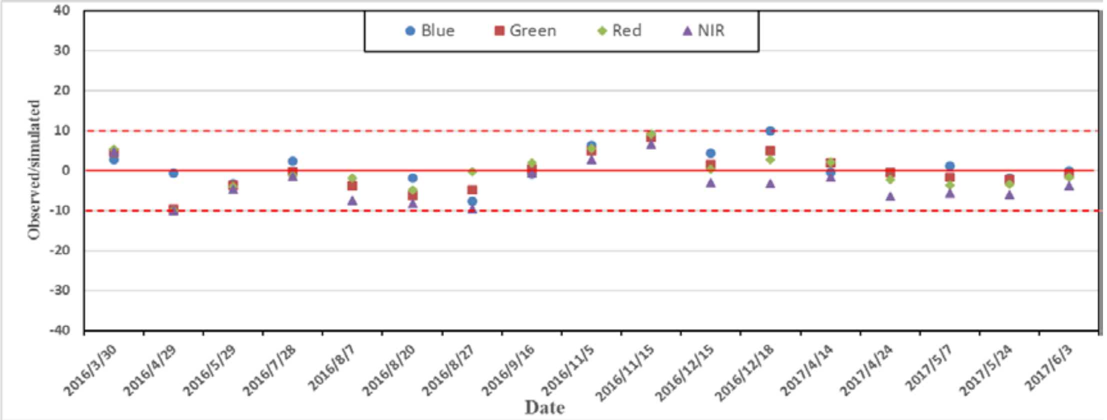


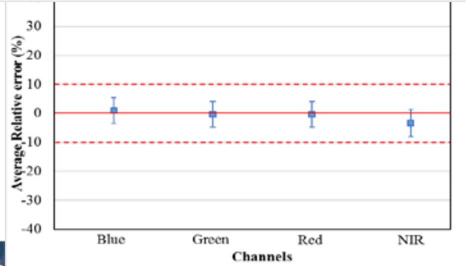
ZY3-02 (Pan:2.1m / MUX:6m)
20 July, 2016

3. Demonstration for Chinese and European satellites

Comparison of RTM simulated TOA reflectance with Sentinel-2a observed reflectance

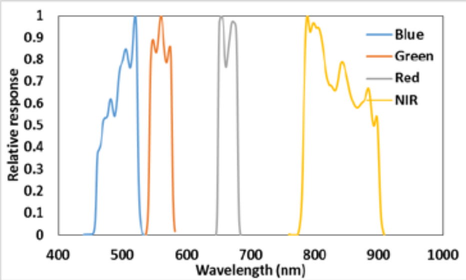
- Over desert（300m*300m, with pure background）





- 17 overpasses are involved in the comparison, which show relative differences of 3.3%, 3.6%, 3.6%, -5.1% for the blue, green, red, NIR band respectively.
- The Sentinel-2a data test told a fact that satellite observations are rather consistent with simulations derived from ground automated measurement.

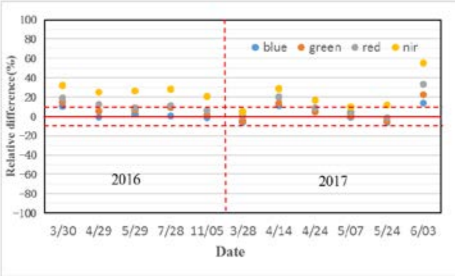
Sentinel 2a

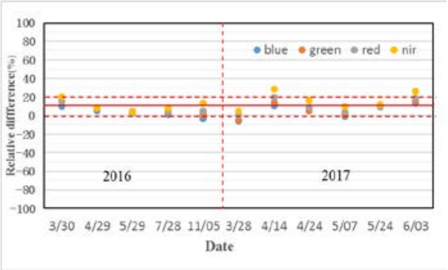


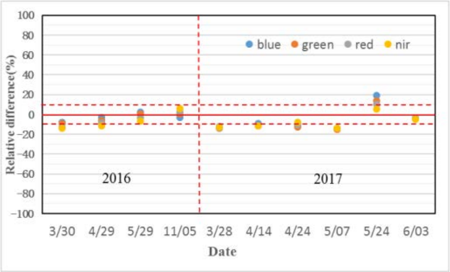
3. Demonstration for Chinese and European satellites

Comparison of RTM simulated TOA reflectance with Sentinel-2a observed reflectance

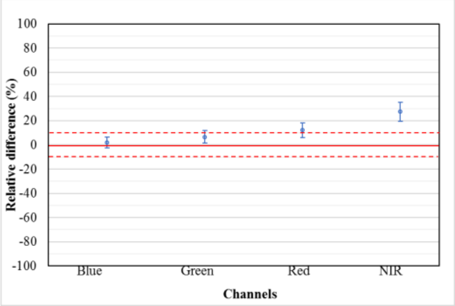
◆ Over artificial target（48m*48m, with relative smaller target & complicated background）

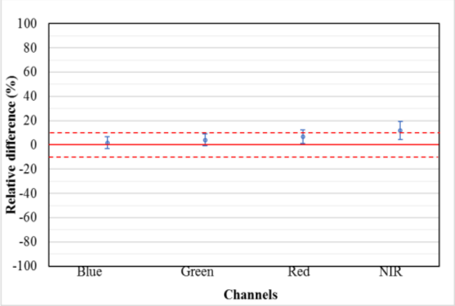


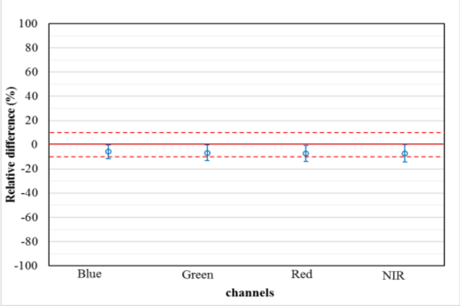




Black target **Gray target** **White target**

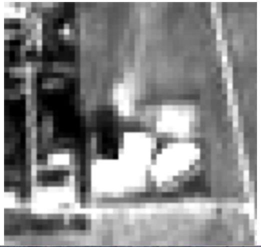






The mean relative differences between the simulation and observation after preliminary adjacent effect correction:

- ✓ Black target: 2.1%, 6.5%, 12.2%, 27.4%.
- ✓ Gray target: 1.8%, 4.1%, 6.7%, 11.8%.
- ✓ White target: -5.8%, -6.5%, -7.2%, -7.1%.

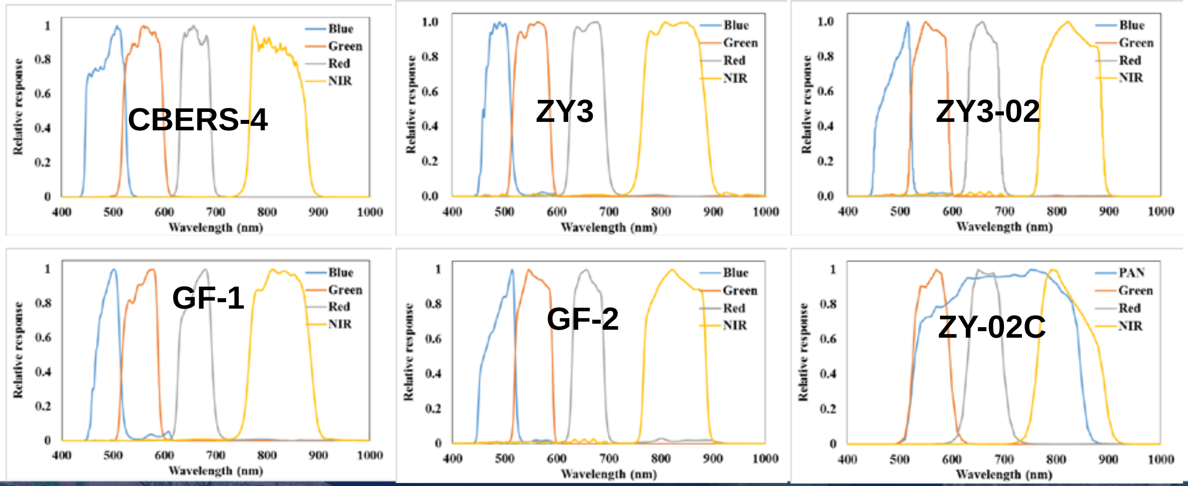


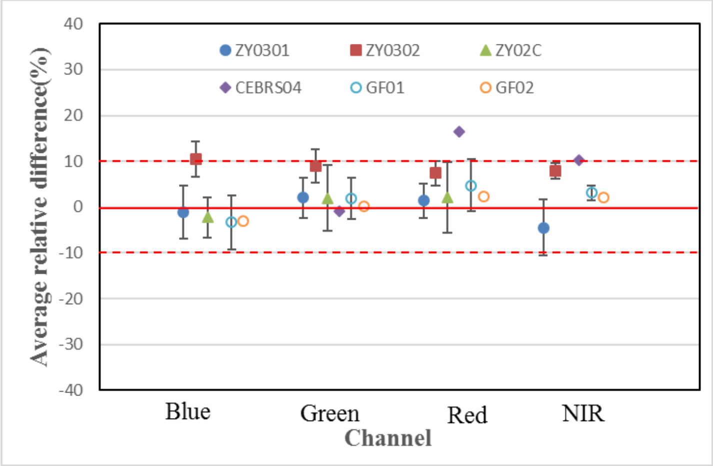
3. Demonstration for Chinese and European satellites

Comparison of RTM simulated TOA reflectance with Chinese high-resolution satellites observation

- Over desert and grey artificial target
  - 27 matchups have acquired, including GF-1, GF-2, ZY3-01, ZY3-02, ZY-02C and CBERS-4.
  - The relative error between simulated and observed TOA reflectance are: 2.0%, 2.2%, 3.3%, 9.2%, 2.1%, 8.7%。

Spectral Response Functions (SRFs)





4. Uncertainty analysis on the standard rad. cal. product

- Many factors, related with the surface, instrument, atmosphere and models, have impacts on the procedure of calibration.

Sources of uncertainty

- **Surface:** Uniformity, stability, BRDF, …
- **Instrument:** Lab calibration, repeatability, …
- **Atmosphere:** AOT, aerosol type, ozone, total precipitable water, temperature profile, humidity profile,…
- **Model:** Radiative transfer model, solar irradiance model, calibration model, …

4. Uncertainty analysis on the standard rad. cal. product

Each site use its own measurement way.
NPL provides each member uncertainty analysis for calibration traceability, to insure each site can provide standard radiometric calibration service with globally consistent quality.

AOE - Baotou

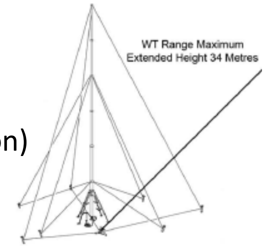
AOE-Baotou

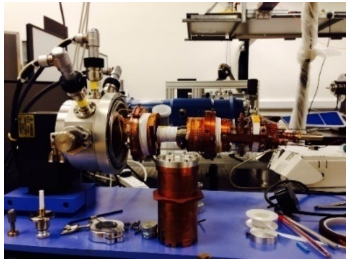
NPL

NASA - Railroad

Valley Playa

ESA - Gobabeb
(under construction)





NPL cryogenic
Radiometer Traceability

CNES - La Crau

4. Uncertainty analysis on the standard rad. cal. product

Uncertainty analysis – Laboratory calibration of spectrometers

- ✓ The spectrometers used in Baotou site are calibrated in NIM (National institute of metrology, China).
- ✓ A lamp-panel system is used in lab calibration. Uncertainty of this system is lower than 2% (k=1).

Uncertainty budget for lamp-panel system (NIM)

Wavelength/nm	300	400	500	600	700	800	900	1000
Repeatability/%	1	0.7	0.5	0.5	0.5	0.5	0.6	0.8
Lamp/%	0.8	0.6	0.4	0.4	0.4	0.4	0.5	0.6
Current %	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Alignment for lamp/%	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Distance %	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Diffuser pannel/%	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Uniformity /%	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Alignment for spectrometer/%	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
nonlinearity %	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Stray light /%	0.8	0.7	0.5	0.5	0.5	0.5	0.5	0.6
Combined U/%(k=1)	**1.84**	**1.56**	**1.32**	**1.32**	**1.32**	**1.32**	**1.4**	**1.57**
Expanded U/% (k=2)	**3.7**	**3.1**	**2.6**	**2.6**	**2.6**	**2.6**	**2.8**	**3.1**

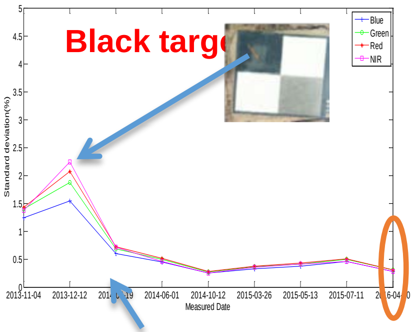
Lab environment

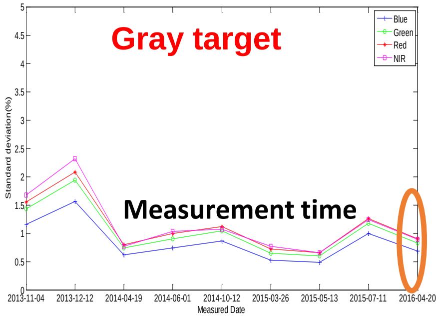
Temperature: 23.9±1.0 ℃

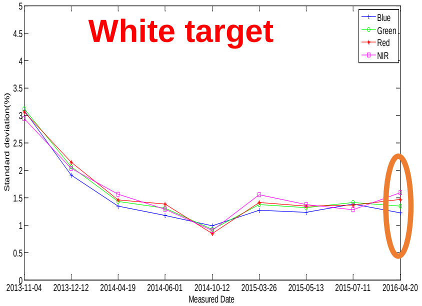
Humidity: 54±2 %RH

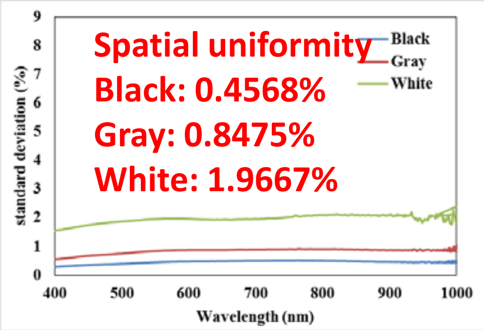
Uncertainty analysis – Surface characteristics measurement and analysis

- The uniformity of targets has been measured and analyzed by random-sampling strategy periodically.
- Till now, the heterogeneity of each target is within 2%.









In-situ data at 11 May, 2017

Washing the black target in April 2014

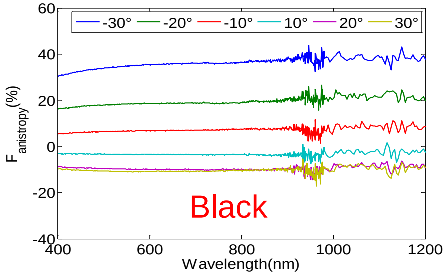
When it didn't rain for long time and the uniformity became worse, artificial washing was performed.

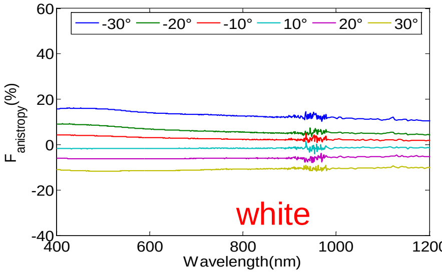
4. Uncertainty analysis on the standard rad. cal. product

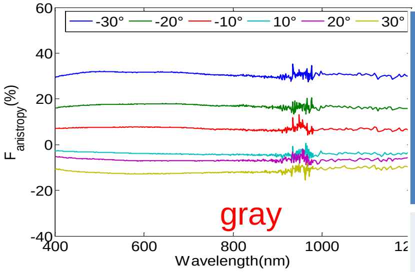
Uncertainty analysis – Surface characteristics measurement and analysis

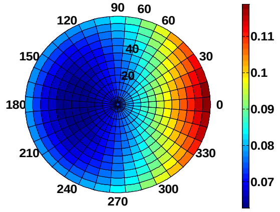
- The BRDFs of different targets have been investigated. The in-situ measurements show that the angular effects can not be neglected. But with Ross-Li model, the BRDF effects can be well decreased.

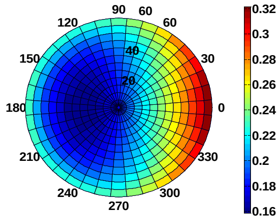
Anisotropy indicator $$F_{anisotropy,\lambda} = 100 * (\rho_{off\_nadir,\lambda} - \rho_{nadir,\lambda}) / \rho_{nadir,\lambda}$$

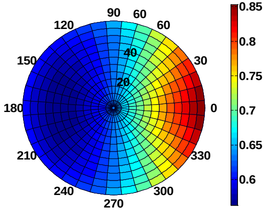










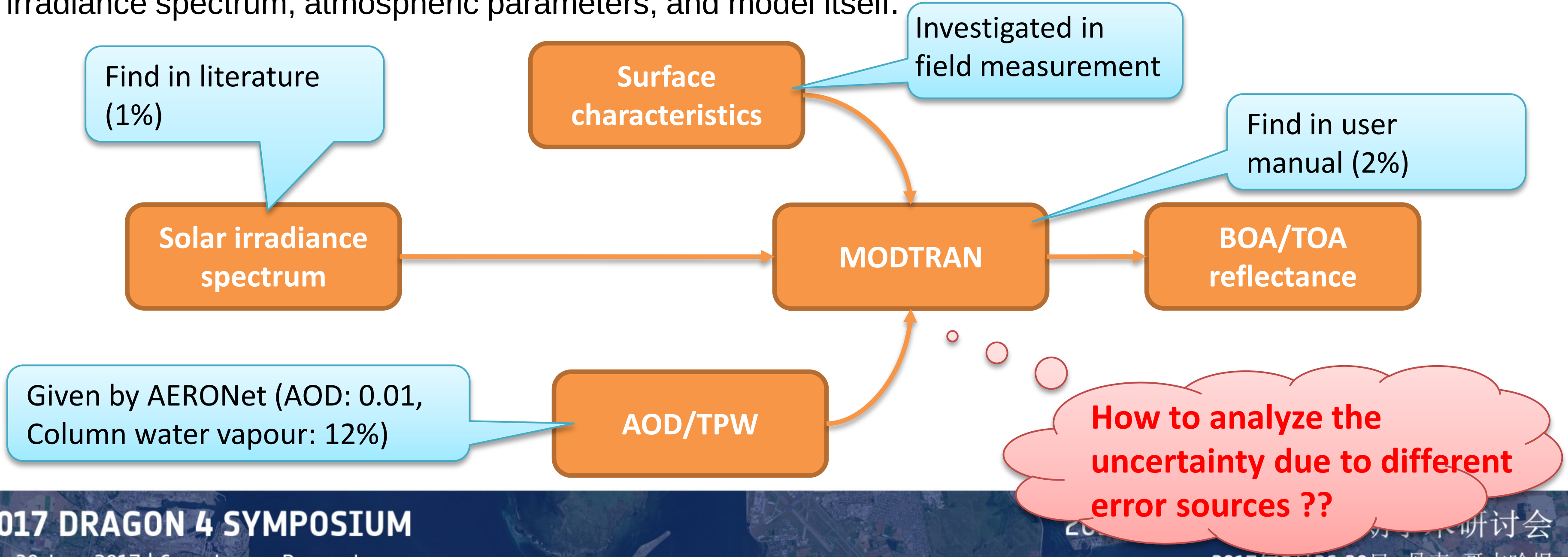


Target	Relative difference		RMSE of BRDF model
	<5°	<10°	
white	1.45%	2.85%	0.24%
gray	2.12%	4.43%	0.67%
black	2.9%	5.54%	0.95%

4. Uncertainty analysis on the standard rad. cal. product

Uncertainty analysis – Uncertainty in atmospheric radiative transfer calculation

✓ The atmospheric radiative transfer model of MODTRAN is used in retrieval of the BOA reflectance and calculation of TOA reflectance/radiance. Errors may introduced by the inputs of model, such as solar irradiance spectrum, atmospheric parameters, and model itself.



4. Uncertainty analysis on the standard rad. cal. product

Uncertainty analysis – Uncertainty in atmospheric radiative transfer calculation

- Generally, the Monte Carlo method is used to analyze the uncertainty when there is a complicate, nonlinear model, such as MODTRAN. But this will cost a lot of time when we want to determine the uncertainty for an observation and calculation.
- We have established an uncertainty LUT for BOA reflectance retrieval for Baotou site.

Structure of LUT for BOA reflectance retrieval for Baotou site

Atmospheric model	Mid-latitude summer, Mid-latitude winter
Aerosol model	Rural
AOD	0.1, 0.2, 0.3, 0.4
Column water vapour (g/cm^2)	1.0, 2.0, 3.0
SZA (°)	20, 30, 40, 60
Spectral range	380nm-2500nm
Spectral interval	10nm

1. For each combination, 2000 groups of random errors are added to TPW and AOD.

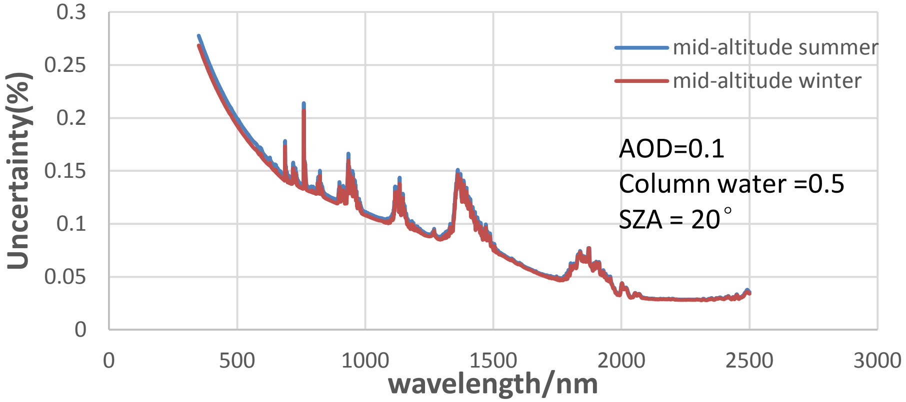
2. Run MODTRAN to get the output

3. Calculate the STD, and this is used as the uncertainty.

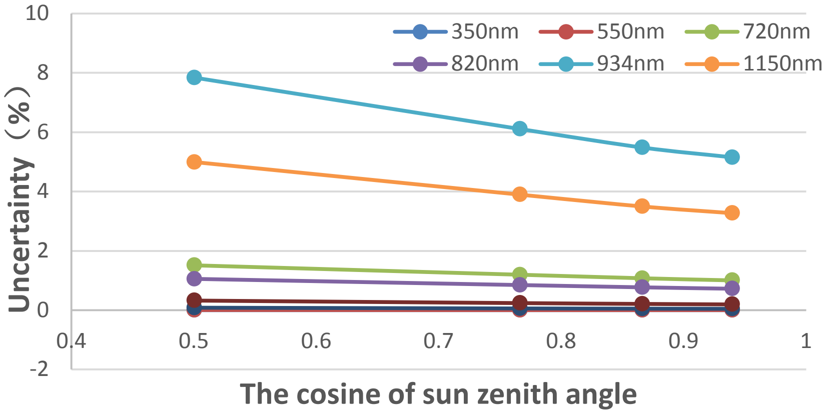
4. Uncertainty analysis on the standard rad. cal. product

Uncertainty analysis – Uncertainty in atmospheric radiative transfer calculation

- Uncertainty is wavelength dependent. But we can find regular variations due to SZA, AOD and TPW.
- Towards a given observation or measurement, the final uncertainty can be efficiently obtained with this LUT using linear interpolation method according to the observation time, atmosphere and observing geometry.



Uncertainties due to different atmospheric model



Uncertainty of BOA radiance due to SZA
（AOD=0.1, Column water=0.5, mid-latitude summer）

4. Uncertainty analysis on the standard rad. cal. product

Uncertainty analysis – Uncertainty combination

For artificial target

Uncertainty component	Sensitivity coefficient	Uncertainty			
		blue	green	red	NIR
Spectrometer calibration	1	2.30%	1.80%	1.80%	1.90%
Spectrometer repeatability	1	0.05%	0.05%	0.05%	0.05%
Target uniformity	1	1.31%	1.79%	2.00%	2.11%
Target BRDF	1	0.91%	1.24%	1.38%	1.46%
Adjacent effect	1	1.51%	1.69%	1.64%	1.67%
AOT	1	0.68%	0.50%	0.30%	0.30%
Column water	1	0.10%	0.10%	0.10%	0.10%
Solar irradiance	1	1.00%	1.00%	1.00%	1.00%
MODTRAN	1	2.00%	2.00%	2.00%	2.00%
Reflectance retrieval	1	2.30%	2.30%	2.40%	2.50%
Spatial scaling	1	0.02%	0.02%	0.03%	0.03%
Combined uncertainty		4.57%	4.61%	4.77%	4.94%

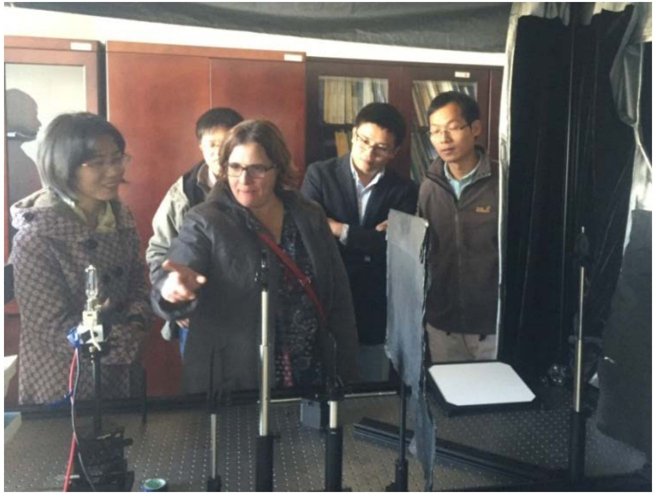
For desert

Uncertainty component	Sensitivity coefficient	Uncertainty			
		blue	green	red	NIR
Spectrometer calibration	1	2.30%	1.80%	1.80%	1.90%
Spectrometer repeatability	1	0.05%	0.05%	0.05%	0.05%
Target uniformity	1	1.01%	1.54%	1.69%	1.80%
Target BRDF	1	0.31%	0.40%	0.41%	0.40%
Adjacent effect	1	0.20%	0.20%	0.20%	0.20%
AOT	1	0.68%	0.50%	0.30%	0.30%
Column water	1	0.10%	0.10%	0.10%	0.10%
Solar irradiance	1	1.00%	1.00%	1.00%	1.00%
MODTRAN	1	2.00%	2.00%	2.00%	2.00%
Reflectance retrieval	1	2.30%	2.30%	2.40%	2.50%
Spatial scaling	1	0.04%	0.03%	0.02%	0.02%
Combined uncertainty		4.15%	4.05%	4.14%	4.29%

ZY-3 02 (20 July, 2016)

Academic Exchanges and Trainings

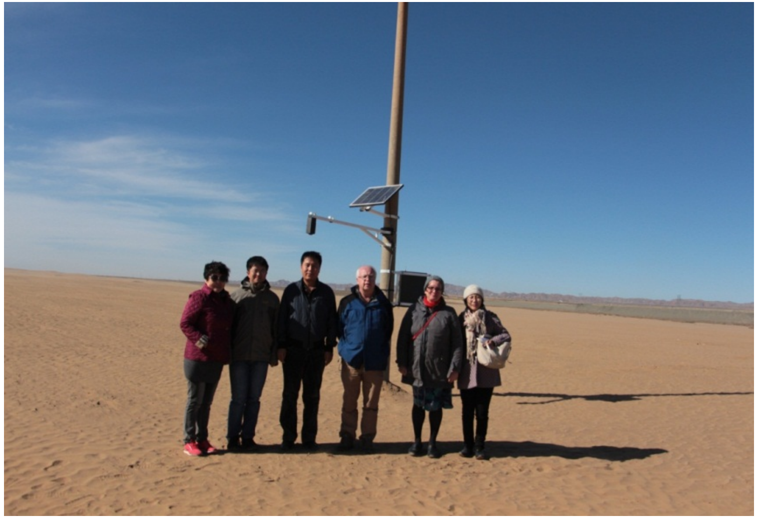
- Dr. Emma Woolliams (NPL) has given the training course on uncertainty analysis for radiometric instrument calibration at AOE.
- AOE researchers will go to NPL and collaborate on writing the uncertainty analysis report of the Baotou site, during July 30 and Aug. 12, 2017.



Academic Exchanges and Trainings

Visiting of the Baotou site

Dr. Steffen Dransfeld (ESA)
Dr. Françoise Viallefont-Robinet (ONERA)
Dr. Esad Micijevic (USGS)
Dr. Hirkazu Yamamoto (GSJ)



Dr. Nigel Fox (NPL)
Dr. Emma Woolliams (NPL)

Academic Exchanges and Trainings

- During July 18-21, the 28th IVOS meeting and 5th RadCalNet workshop were held by AOE in Beijing. Nearly 30 representatives, from ESA, CNES, DLR, NPL, NASA, NOAA, CSIRO, ONERA, GSJ, AOE etc., attended the meetings.

- Teleconferences were held in each quarter among the RadCalNet members, in order to discuss work progress, technical problems, etc.

5. Future Work

1. To improve the calibration accuracy

- Improve surface reflectance retrieval method, with the irradiance observation.
- To make more efforts to solve the adjacent effect problem of artificial targets.
- Development of the local atmospheric model：Explore the information from historical data to find the characteristics of the local atmosphere and surface.

2. To upgrade consistent traceable approach for quality control

- To enhance the traceability of the spectrum measurement system, a automated surface spectral reflectance measurement system for short-wave infrared spectrum will be manufactured and installed in Baotou site.
- Complete the error budget, and try to achieve the goals of data quality traceability and efficient quality control for the input files.

3. To offer contribution to the “global calibration” of EO satellites through RadCalNet

- To re-process the measurements according to the new RadCalNet templete;
- To perform new round Beta user test of automated radiometric calibration under the framework of RadCalNet and Dragon programme.

Thank you for your attention!

1. Background & Motivation

22 Institutions:

11 Institutions

ESRIN-ESA
NPL, UK
University of Valencia, Spain
University of Strasbourg, France
University College London
Vanderbilt University, US
CLS, France
Informus GmbH, Germany
BIRA-IASB, Belgium
DLR, Germany
Aristotle University of Thessaloniki, Greece

11 Institutions

AOE-CAS
NIM
NSMC-CMA
AIOFM-CAS
SITP-CAS
CRESDA
Siwei company
SIOM-CAS
Ocean University of China
IE-CAS
IAP-CAS