Radiometric Calibration Based on Chinese Radiometric Calibration Site(CRCS) at Dunhuang

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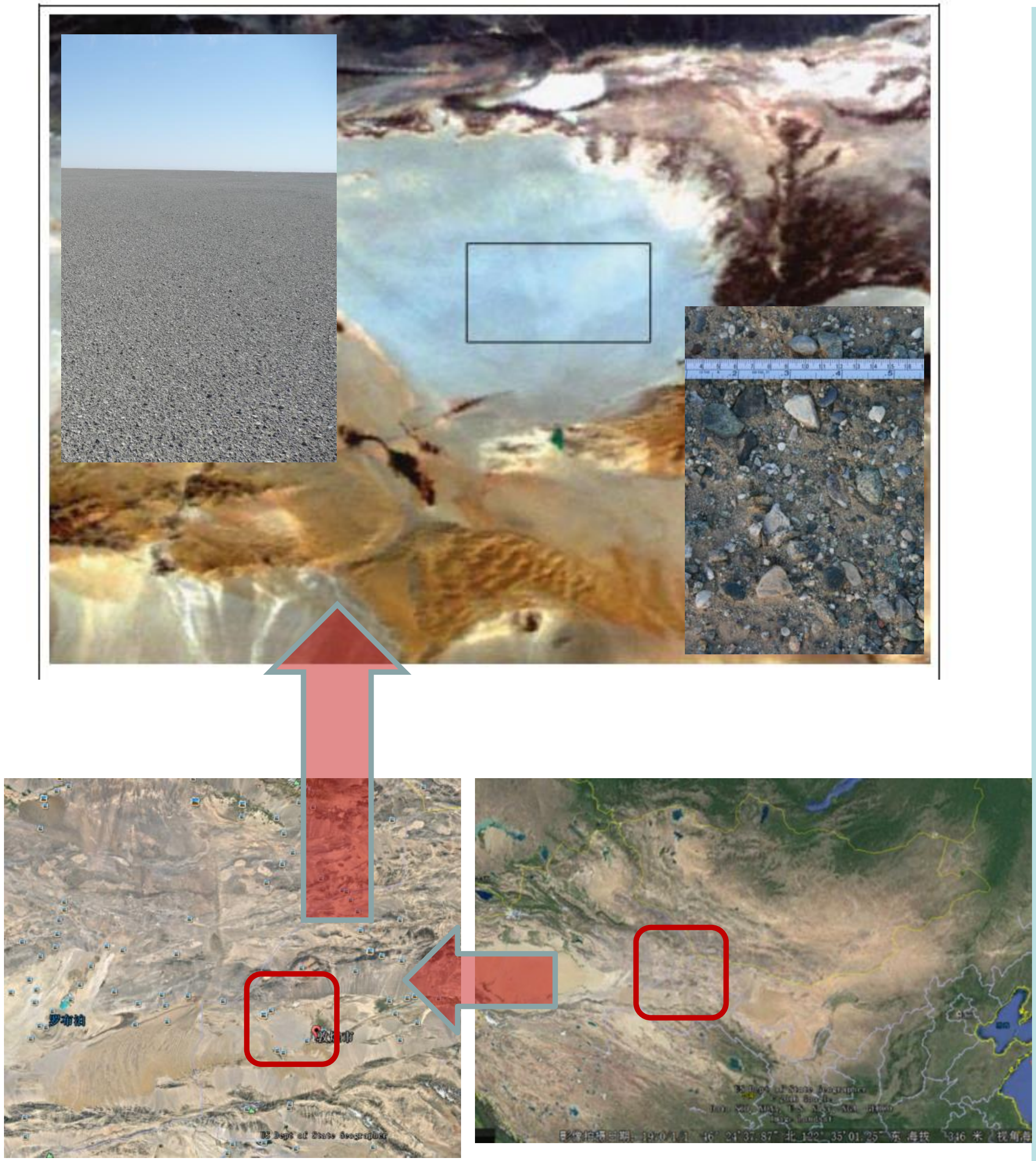
NSMC

Outline

- **Introduction of Dunhuang Chinese Radiometric Calibration Site(CRCS) and method for CAL/VAL**
  - Characteristic of Dunhuang Site
  - Surface reflectance measurements
  - Atmospheric parameters observations
  - VIS-NIR Cal/Val Assessment by AQUA/MODIS and NPP/VIIRS
- **Ground-based Automatic Observation Systems on Dunhuang Site**
  - Arrangement for the field observing station
  - Introduction of automatic observation instruments
  - Primary results based on the automatic observation systems

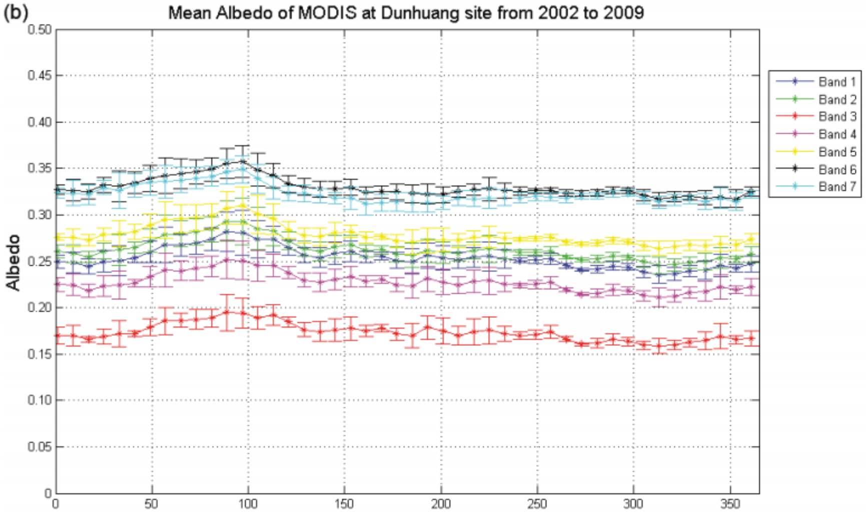
1. OVerview of Dunhuang Chinese Radiometric Calibration Site(CRCS)



Dunhuang Site: Located at Gobi desert in northwest part of China. Covering approximatly 30km*30km.Gobi surface is combined with sandy soil and gravels. The mean diameter of the gravels is from 2cm to 5cm.

It is one of the China Radiometric Calibration Sites (CRCS) used for the RSB vicarious calibration (VC) of Chinese space-born sensors, and was selected in 2008 by the Working Group on Calibration and Validation (WGCV) of the Committee on Earth Observation Satellites (CEOS) as one of the instrumented reference sites.

Features of Dunhuang Site



Trend and temporal deviation of surface reflectance BRDF–albedo of bands 1–7 at the Dunhuang site from MODIS MOD43 product:

Generally speaking, the stability of surface albedo of Dunhuang is good except in spring season perhase due to the snow melting.

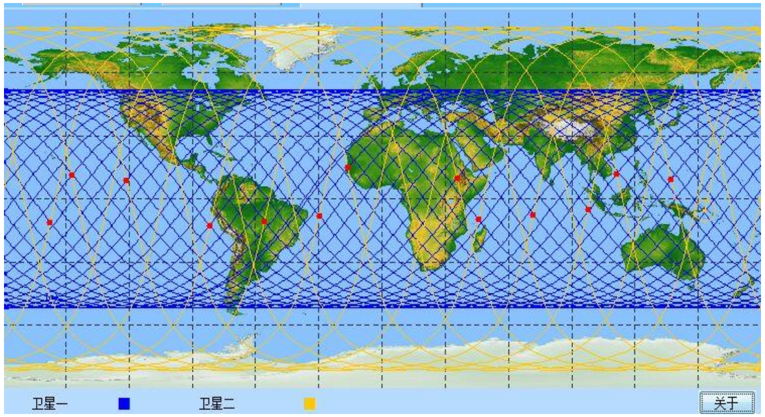
Feature Parameters		CRCS Dunhuang Site
Location		Dunhuang City, Gansu Province 40.1821° N, 94.3244° E
Altitude		1160m
Area		30km×30km
Surface feature		Gobi desert without vegetations
Climate type		Dry continental climate
Averaged annual meteorological parameters	surface pressure	887.6hpa
	surface air temperature	9.5℃
	Annual precipitation	34.1mm
	Surface relative humidity	43.9%
	Annual sunshine time	3270 hours
	Annual clear days	112.2 days
	Days of visibility larger than 10km	288.2 days
Reflectivity in VIS/NIR channels		15%—30%

The atmospheric conditions are dry and clean. It is a very good radiometric calibration site for satellites.

Take 2015 CRCS calibration experiment campaign for example

◆ Reflectance-based VC method

- ◆ ***Surface reflectance observations***
- ◆ ***Atmospheric parameters observations (Aerosol, Watervapor, O3)***
- ◆ ***6SV radiative transfer model***

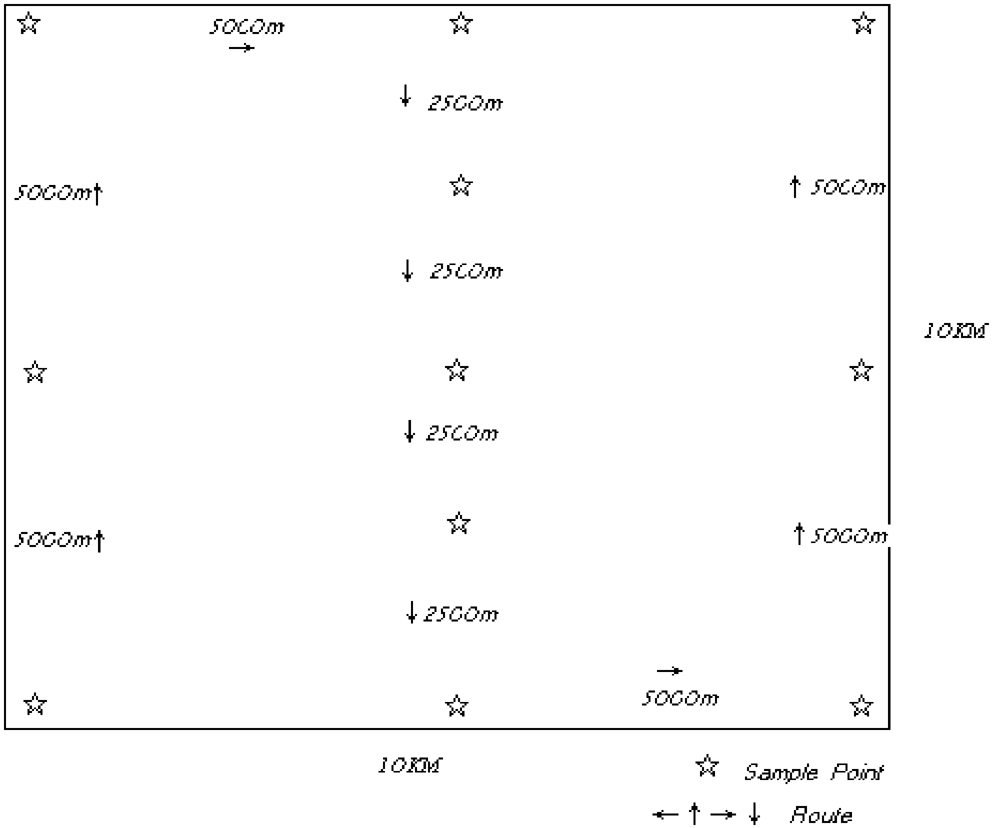


Satellite overpass forcast (select the satellite View Zentih Angle less than 30°)to decide which day is suitable for calibration

VC activity team is mainly divided into 2 groups. One group is responsible for the atmospheric parameters measurements, including aerosol optical depth, water vapor content, total ozone column, temperature, pressure, humility, cloud mount and so on.

The other group is responsible for the surface reflectance measurements by the spectroradiometer.

Scheme for surface reflectance measurement



Dunhuang CRCS central area is 10km*10km. This central area is divided into several sections with 11 measurement spots.

the surface reflectance is measured by the spectroradiometer. In each calibration process, a ASD FieldSpec3 spectral radiometer carried on the vehicle transported through the center of each subarea of this site, measures the surface reflectance within 1.5 hours during the satellite over-pass.

Measurement of surface reflectance and BRDF correction

The directional reflectance was measured by ASD FieldSpec3 spectral radiometer and standard reference board (SRB) which has a lambert reflection surface.

A great deal of data for the retrieval of the Dunhuang site BRDF model was obtained during the field missions in 2008 and 2013. The BRDF measurement system intends to provide quasisimultaneous, multiangle, multispectral measurements of the Earth surface reflected solar radiance. The BRDF model adopts the MODIS BRDF model Algorithm for Model Bidirectional Re-flectance Anisotropies of the Land Surface (AMBRALS)

2008

BRDF

$$R(\theta,\phi,\varphi,\lambda) = f_{iso}(\lambda) + f_{vol}(\lambda) * k_{vol}(\theta,\phi,\varphi) + f_{geo}(\lambda) * k_{geo}(\theta,\phi,\varphi)$$

Ref correction

$$R_{cor}(\theta_s,\phi_s,\varphi_s,\lambda) = R_{mea}(\theta_m,\phi_m,\varphi_m,\lambda) * R_{mod}(\theta_s,\phi_s,\varphi_s,\lambda) / R_{mod}(\theta_m,\phi_m,\varphi_m,\lambda)$$

Due to the time between surface reflectance measurements and satellite observation is not simultaneously, the surface reflectance of each spots should be corrected to the same angle condition with satellite observation by the BRDF model using above equation

2013

Figure 6 DREF measurement by PDMS

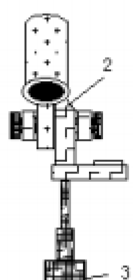


Figure 7 Structure of PDMS (side view)

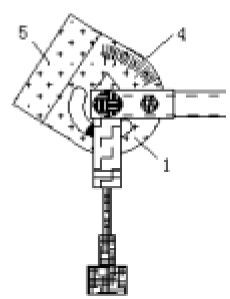


Figure 8 Structure of PDMS (front view)

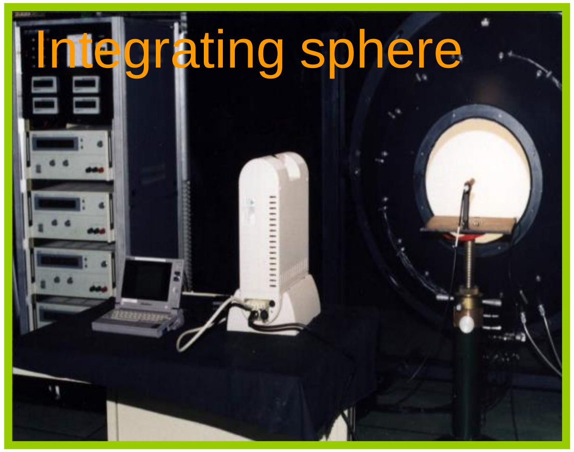
Portable BRDF measurement instrument

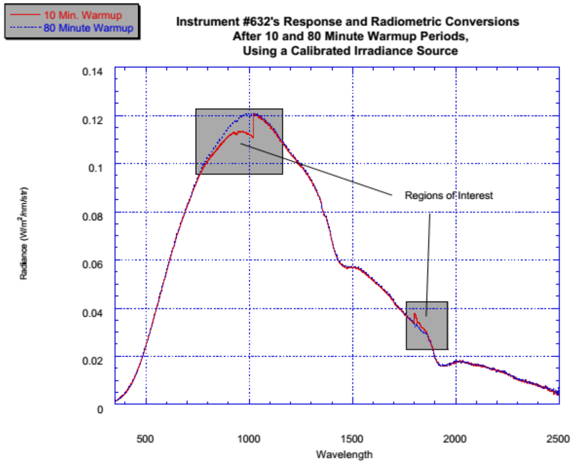
The main performance parameters of the ASD FieldSpec® 3 spectroradiometer

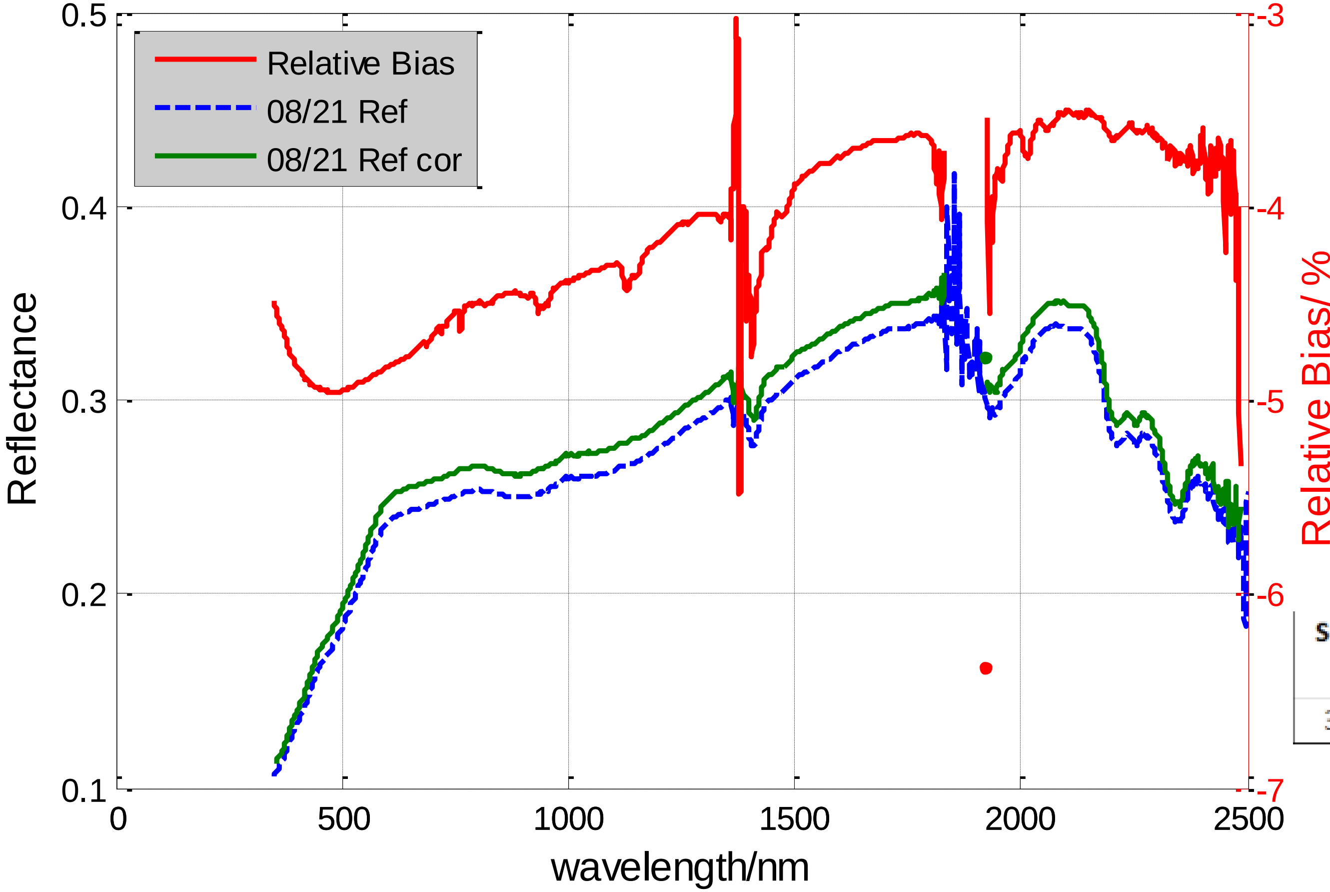
Wavelength range	350-2500nm		
Sample interval	10^{-1} Second		
Linearity	±1%		
FOV	Bare, 1°,10°		
Spectra region	VNIR	SWIR1	SWIR2
Detector	512 element silicon photo-diode array	InGaAs photo-diode	InGaAs photo-diode
Spectral region	350nm-1000 nm	1000nm-1830 nm	1830nm-2500 nm
FWHM	3nm at 700 nm	10nm at 1400 nm	10nm at 2100 nm

The FieldSpec 3 is a product of Analytical Spectra Devices Inc(ASD). It is a highly portable, general purpose spectroradiometer useful in many applications requiring either the absolute or relative measurement.

The detailed parameters were shown in table . ASD FieldSpec 3 has been well calibrated before it was delivered from the factory and we also did radiometric calibration in our laboratory before we started the campaign.







SolZ(°)	SenZ(°)	SolA(°)	SenA(°)
30.07	25.62	-154.95	76.58

Figure shows the surface reflectance of measurement spot No.6 before(blue dash line) and after(green line) BRDF correction and their relative bias(red line). The relative bias between these two reflectance is about 4%~5%. Between the gap of each ASD spectra detector, there are some noises which could affect the calibration accuracy of specific bands near the gap.

Instruments for atmosphere measurement

- Purpose：atmospheric measurements
- Location：Site No.1
- Instruments：

① Sun-photometer CE318：Aerosol optical depth;

② Sun-irradiance：Total irradiance、Diffuse irradiance

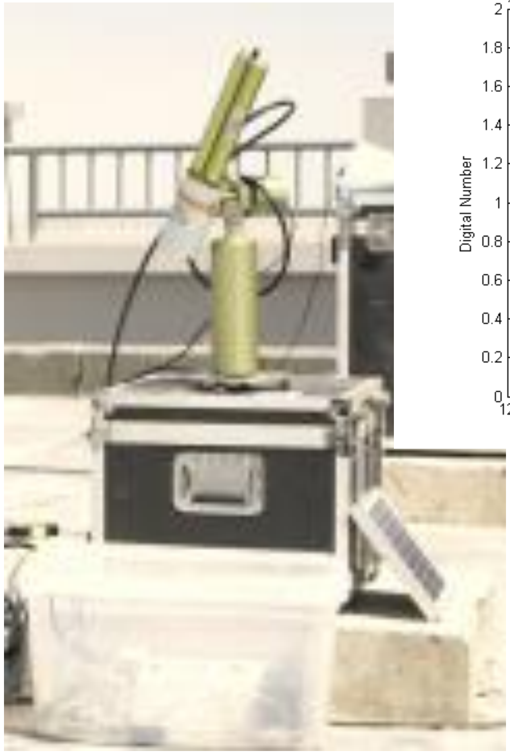
③ Portable sun-photometer-MICROTOP ：Aerosol；O_3

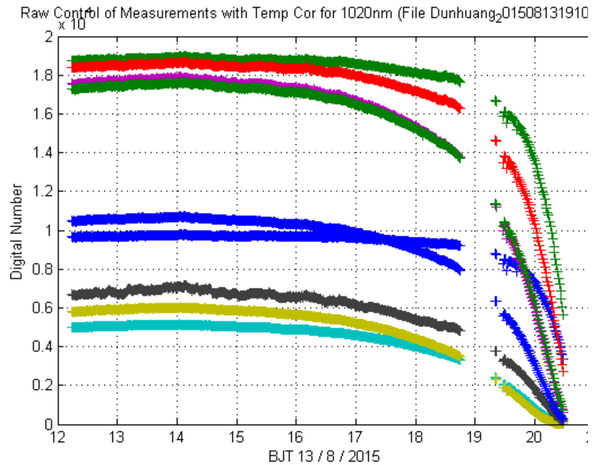
④ Portable meteorological instrument：Pressure、Humity、Temperature、wind parameters in site;

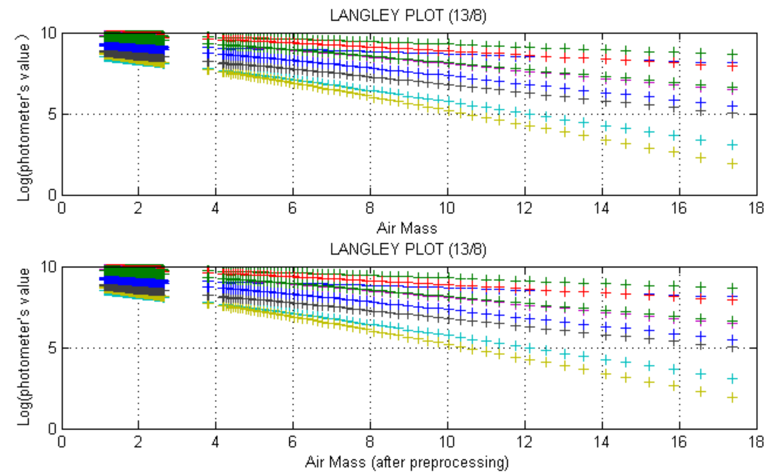
⑤ Fisheye camera：cloud mount

⑥ Radio sonde（In Dunhuang Meteorology Bureau）：P/T/H profile

Sun-photometer-CE-318

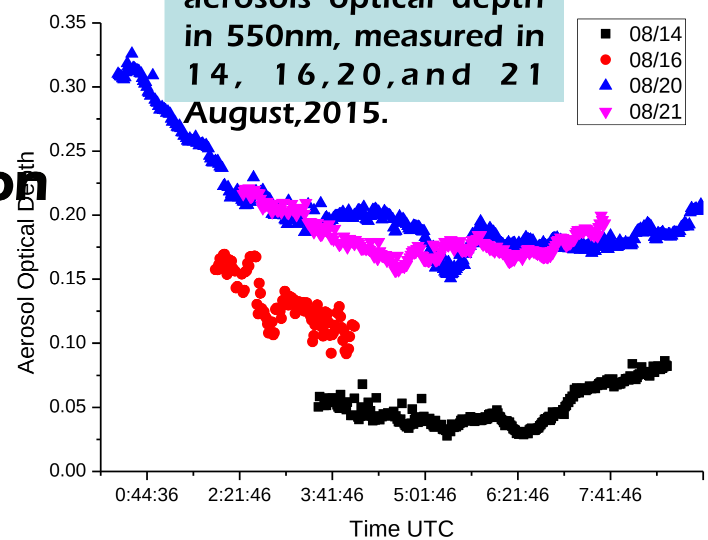






CE-318 is a sunphotometer which is world widely used in aerosol optical depth(AOD) measurement. The langley method was used for the instrument calibration. The AOD was obtained by one minute.

aerosols optical depth in 550nm, measured in 14, 16,20,and 21 August,2015.



Usually, the AOD used for VC is the mean value of AOD within and after half an hour of the satellite over passed.

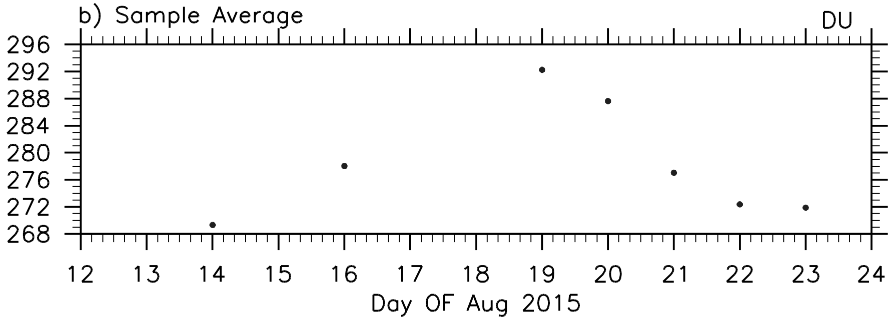
Langley method for calibration

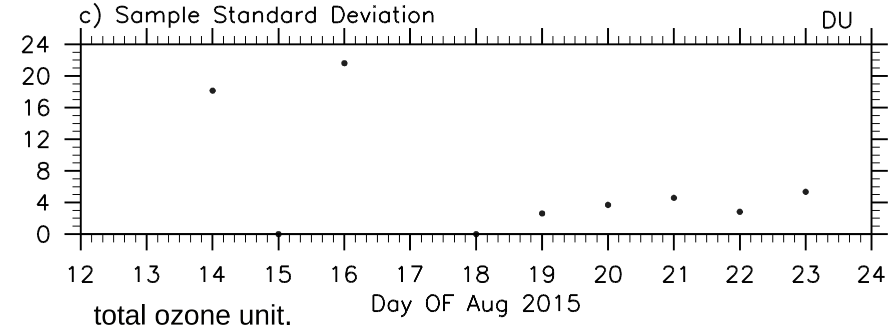
$$E = E_0 R^{-2} \cdot \exp(-m\tau) T_g$$

logarithm

Y=a*x+b

Portable sun-photometer-MICROTOP



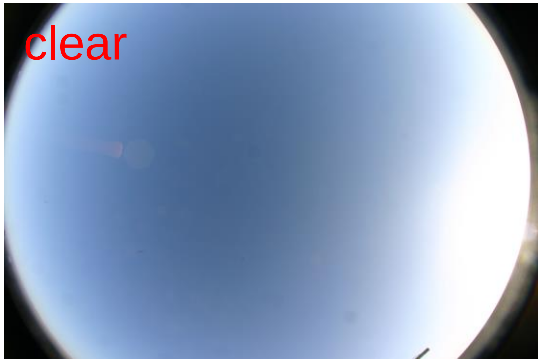


total ozone unit.

Besides the automatic sunphotometer, a portable sun-photometer named MICROTOP was also used in the CRCS campaign.

Portable meteorological instrument

Record the temperature, water-vapor, pressure, windspeed on the ground



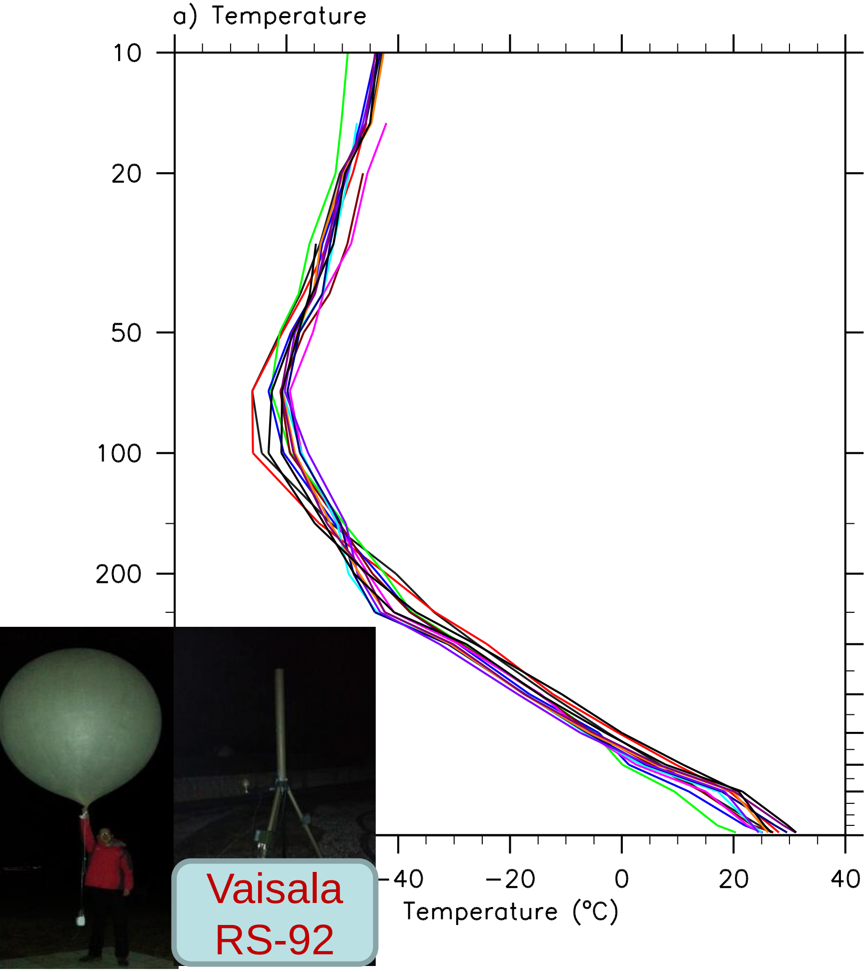
Photograph of the atmosphere condition by a fish-eye camera

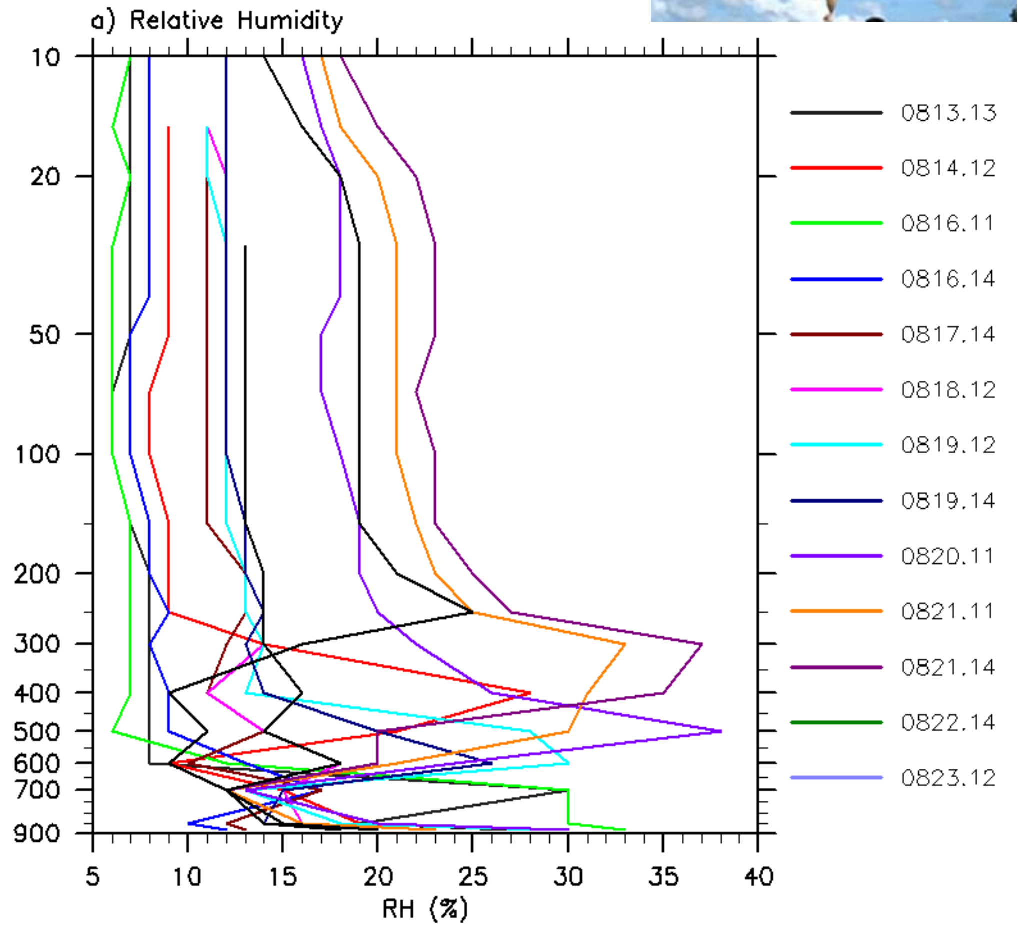
Record for meteorology parametres

Date	Time	Tem	Hum (%)	Pre (hpa)	Windspeed (m/s)
2015-8-13	14:00	31.8	14.4	870.9	1.2
2015-8-13	14:25	32.9	12.1	870.2	1.4
2015-8-13	14:45	34.0	11.5	870.2	2.0
2015-8-13	15:09	34.3	12.2	869.5	1.4
2015-8-13	15:28	34.6	13.6	869.4	0.9
2015-8-13	15:57	33.0	12.9	869.1	4.5

Radio sonde

When the satellite passed, a radiosonde was launched by balloon in Dunhuang Meteorology Observation Station which is about 25km east from Dunhuang CRCS site. The temperature and watervapor profile were gotten by the radiosonde. Total watervapor content is the sum of the watervapor profile.





Vicarious calibration method

- **Reflectance-based VC**

Apparent reflectance observed by satellite is involved into two parts: surface part and atmospheric part

$$\rho_{atm} = T^{O_3} T^{og} \left[(\rho_{R+A} - \rho_R(P_0)) T^{\frac{1}{2} H_2O} + \rho_R(P) \right]$$

$$\rho_{toa} = \rho_{atm} + \rho_{surf}$$

$$\rho_{surf} = T^{O_3} T^{og} T^{H_2O} \left[T^{\downarrow}_{R+A} T^{\uparrow}_{R+A} \frac{\rho_{lambertian}}{1 - S_{R+A}\rho_{lambertian}} + \rho_{brdf} \right]$$

The vicarious calibration method using natural earth scenes has been widely used since it was developed by the Remote Sensing Group of the University of Arizona(Slater et al., 1987) in the 1980s.

RTM： 6Sv
Input Parameters：surface reflectance；aerosol optical depth;Total Ozone Unit; Watervapor content
Satellite data：MODIS/Aqua C6 MYD1km；VIIRS/NPP；

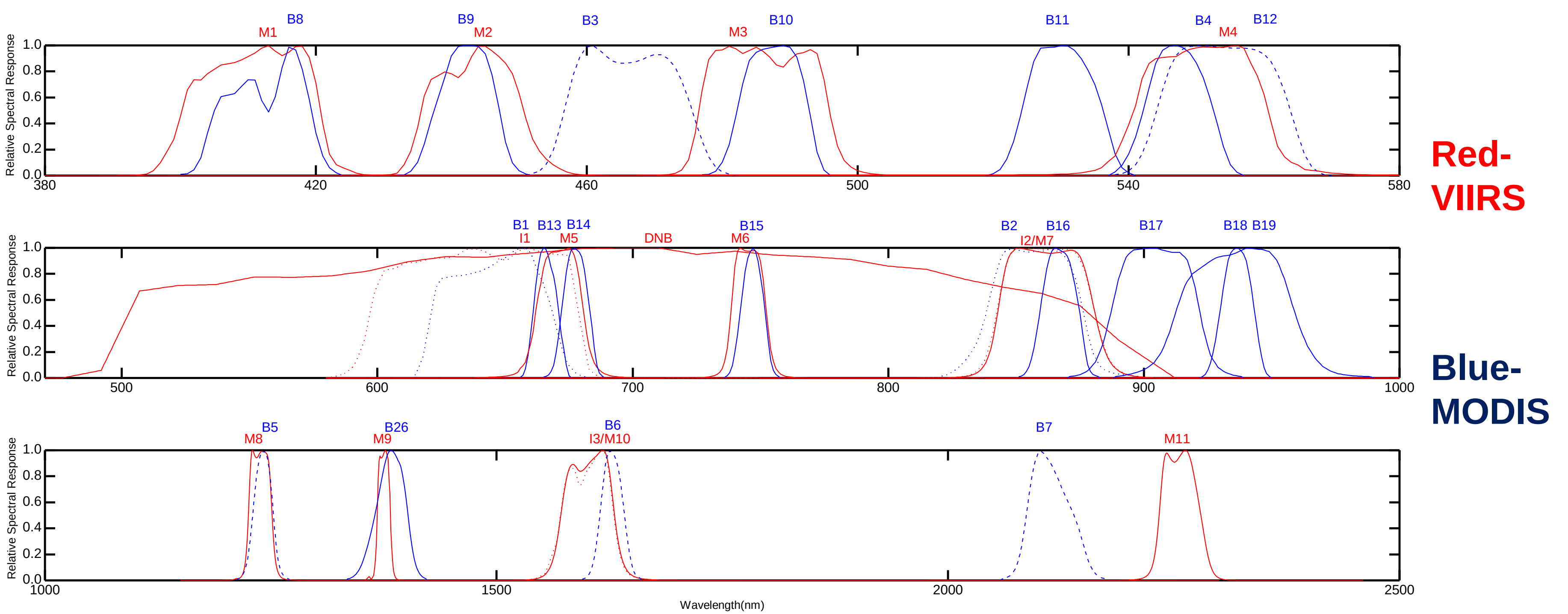
$Bias(\%)=100(Ref_{Mea}-Ref_{Cal})/Ref_{Cal}$
$Uncertainty=STD(Bias_n)$ n=1:11;

Atmospheric parameters and sensor angles information

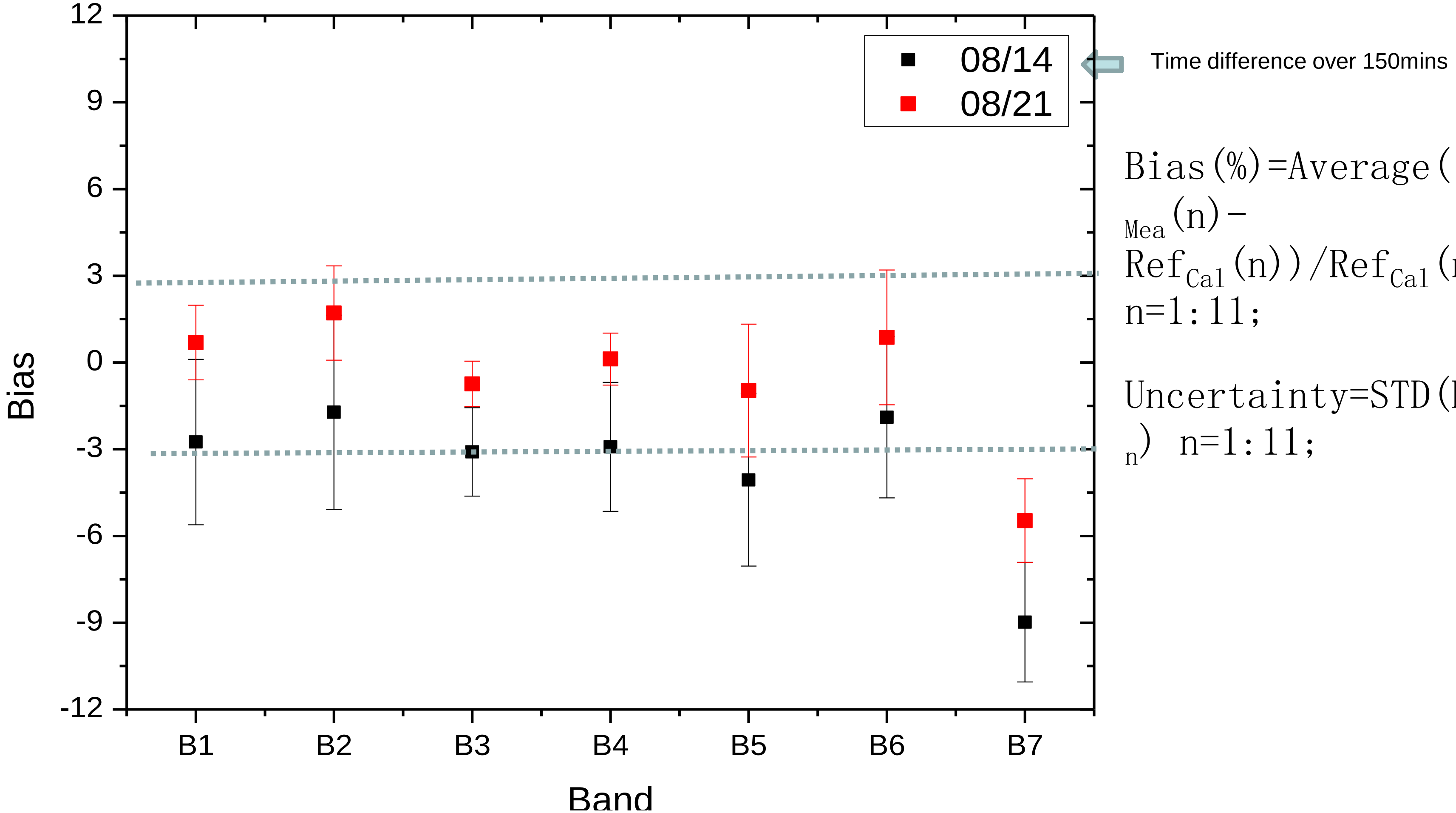
Sensor	Date	τ_a(550)	Time Difference(min)*	WV(g/cm^2)	Ozone (cm-atm)	SolZ(°)	SenZ(°)	SolA(°)	SenA(°)
VIIRS	08.16	0.1290	33	0.5632	0.2787	29.38	7.15	-149.56	-100.31
	08.21	0.1722	8	1.2895	0.2746	31.59	16.95	-147.67	-100.69
MODIS	08.14	0.0564	151	1.3251	0.2755	27.35	34.55	-157.09	76.27
	08.21	0.1824	16	1.2895	0.2732	30.07	25.62	-154.95	76.58

***** *It means that the Difference Time between the time of surface reflectance measurements in the center of site and the time of satellite over pass***

Four days in-situ measurements data including two days for VIIRS and two day for MODIS were used for this evaluation.



Assessment VIS-NIR calibration for AQUA/MODIS



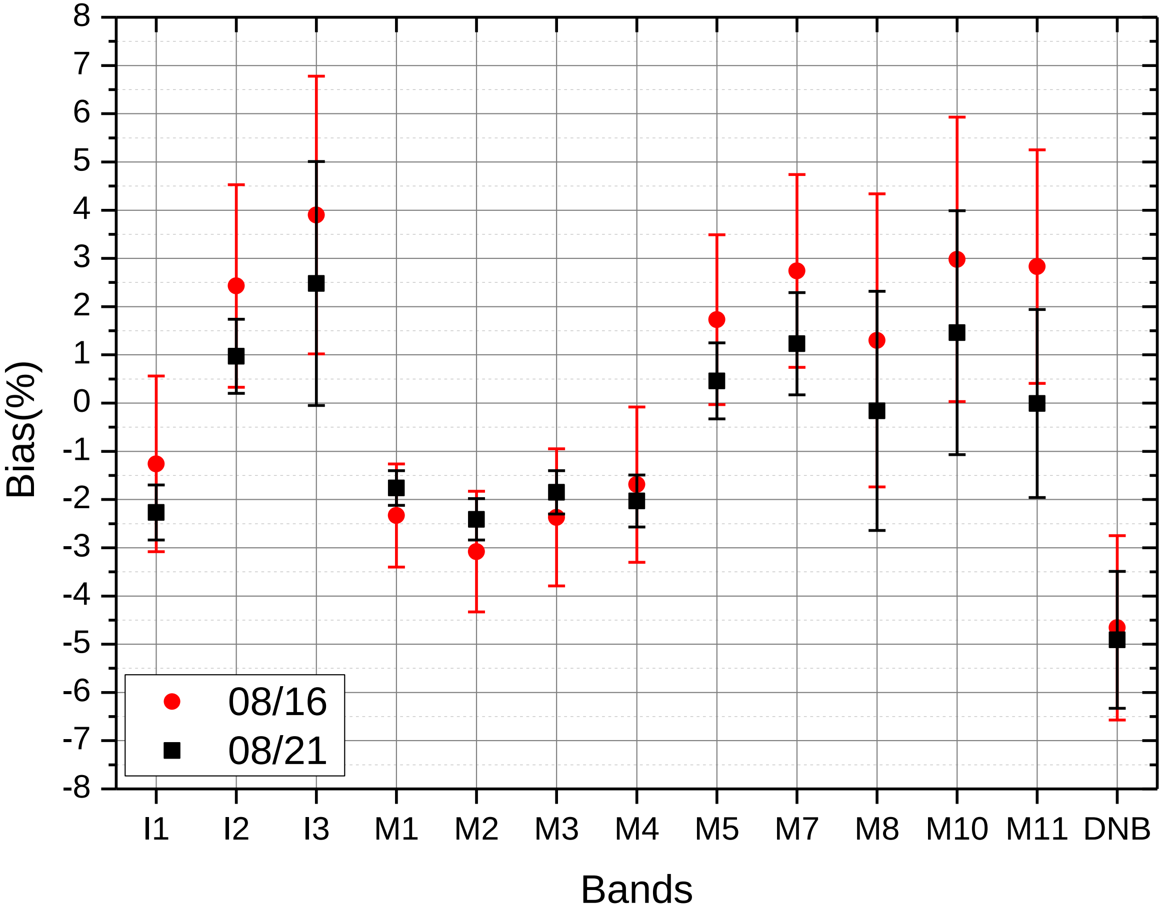
$Bias(\%) = Average((Ref_{Mea}(n) - Ref_{Cal}(n))/Ref_{Cal}(n))$ n=1:11;

$Uncertainty = STD(Bias_n)$ n=1:11;

1. 21, Aug: The bias is within 2%(max 1.71% B2, min 0.12% B4) for all bands except B7(-5.5%). The uncertainties of all bands are less than 2.5%.

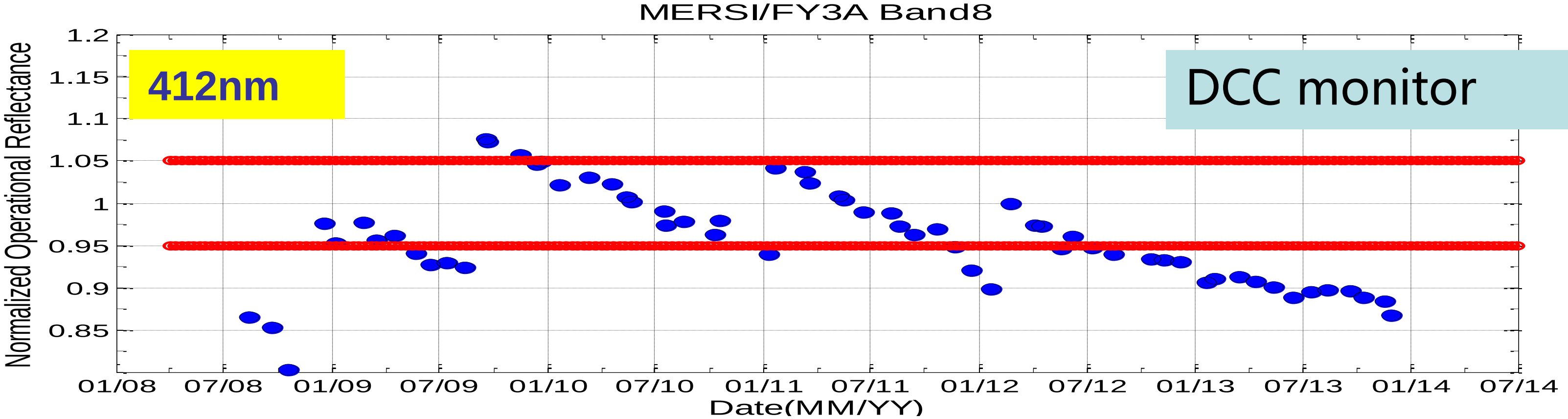
2. 14, Aug: The results are systemic lower. The time difference between the surface measurement and satellite pass is over 150min. On that day, we measured before noon, but Aqua passed afternoon.

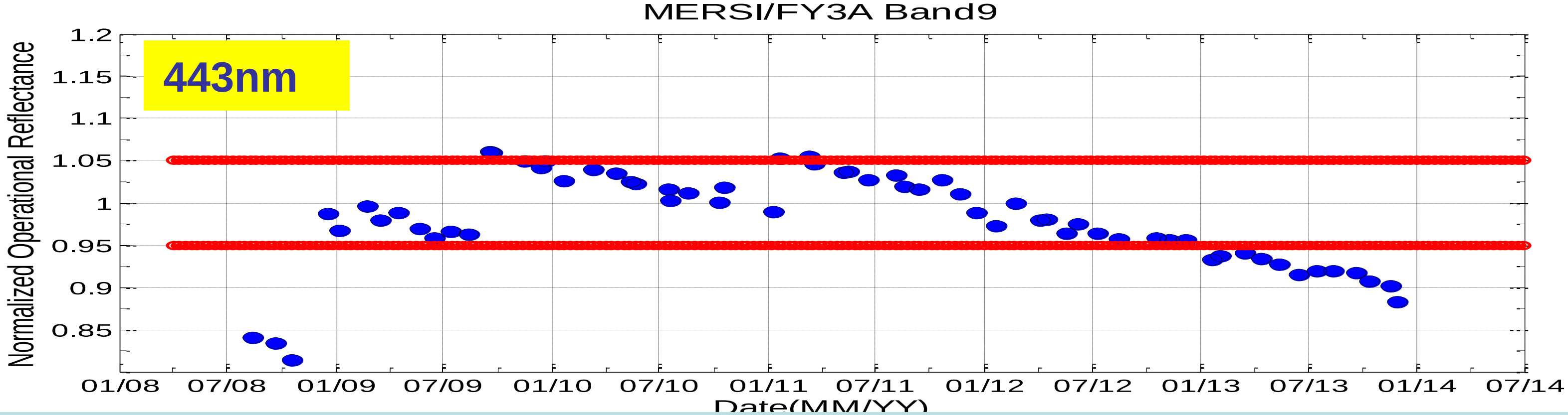
Assessment VIS-NIR calibration for VIIRS/NPP



1. The biases for all bands are within 3% except DNB band.
2. The uncertainties of all bands are less than 2.5% except I3,M8 and M10 in Agu.16
3. There are good agreements of the two days results except M11 that shows the larger uncertainty in short-wave infrared band (SWIR) calibration.
4. The bias of DNB band is slightly larger than the other RSBs. But it is stillt within the designed specification(10%).

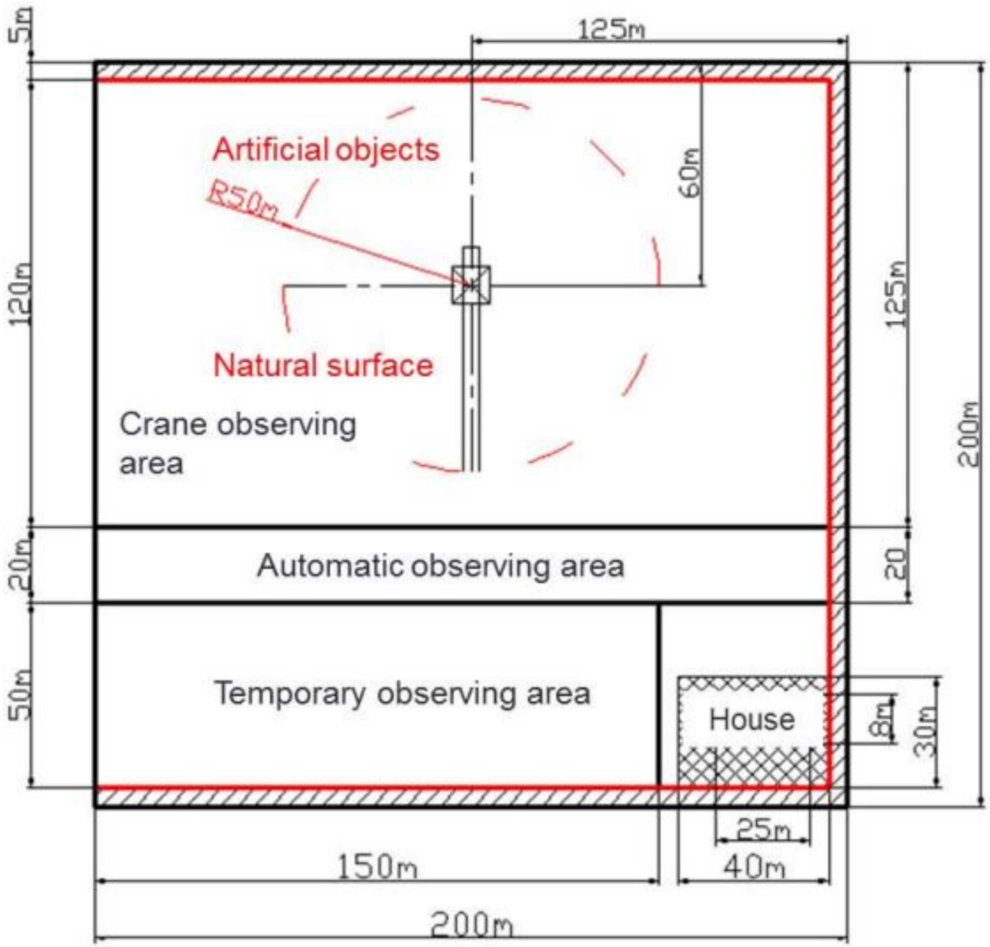
2. Ground-based Automatic Observation Systems on Dunhuang Site -Motivation





- Reflectance-based VC using the CRCS Dunhuang site has been the baseline method of operational calibration since 2008 for FY3 ; It was done once a year, however.
- The annual degradation of a sensor could be more 10%. So the update cal efficiancy could not meet the quantitative demand。
- Collecting synchronous in-situ measurements for a satellite sensor radiometric calibration is expensive and time-consuming.

2. Ground-based Automatic Observation Systems on Dunhuang Site-Design of the observing field

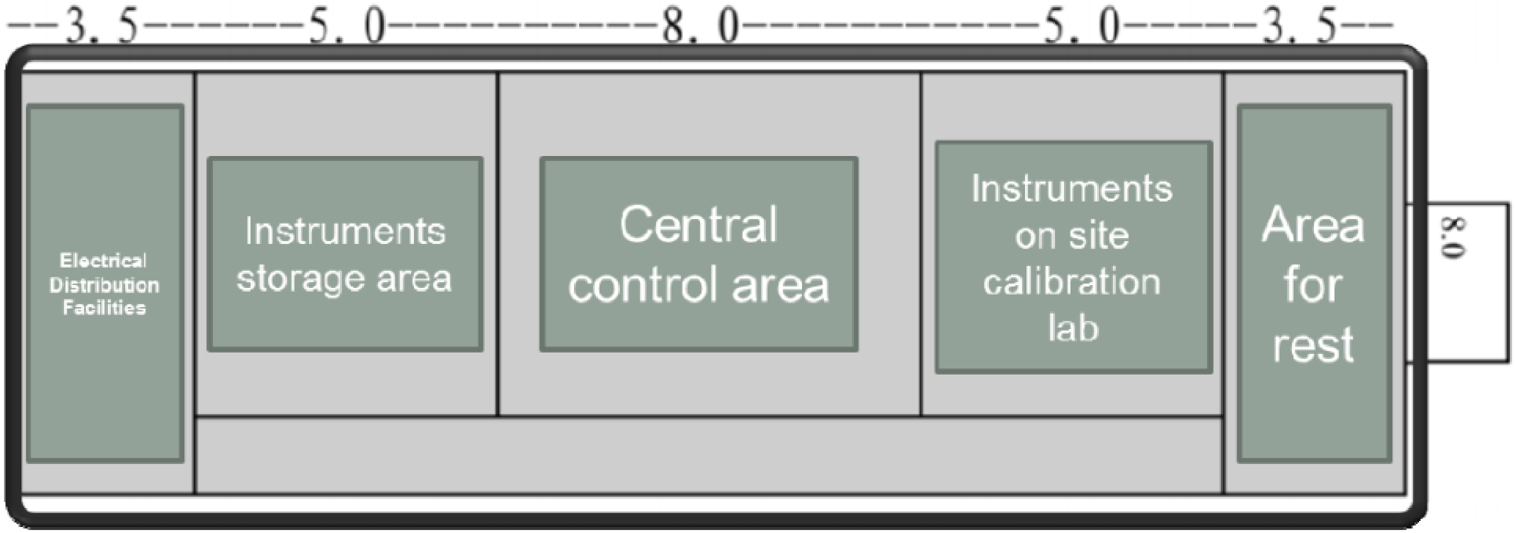


In order to resolve these problems, a new automatic observation station was built at CRCS Dunhuang site. The field observing station was composed by house, observing field, instrument platforms,power supply, tower crane, road to the station and safeguard facilities.

There is a 200m × 200m observing field. In this area, three functional parts include crane observing area, automatic observing area and temporary observing area.

The house is located in the southeast corner of the observing field. The crane observing area is also divided into two parts: north part of the circle area is artificial objects and south part of the circle is natural Gobi surface.

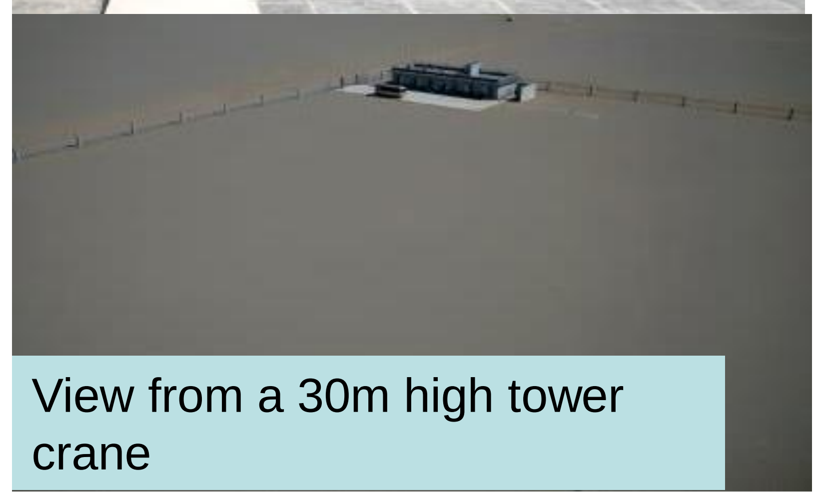
Design of the house



There are 5 function divisions: electrical distribution facilities, instruments storage area, central control area, instruments on site calibration lab and rest area. The house is 3.5 meters height, 25 meters long and 8 meters wide, totally 200 m2.

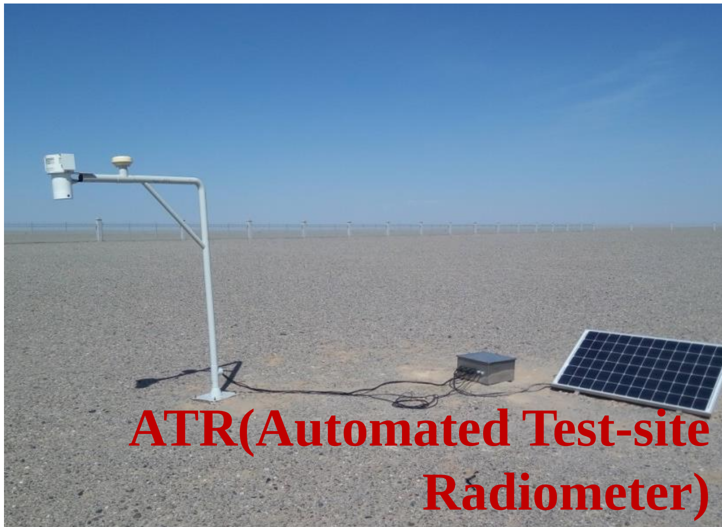
2014

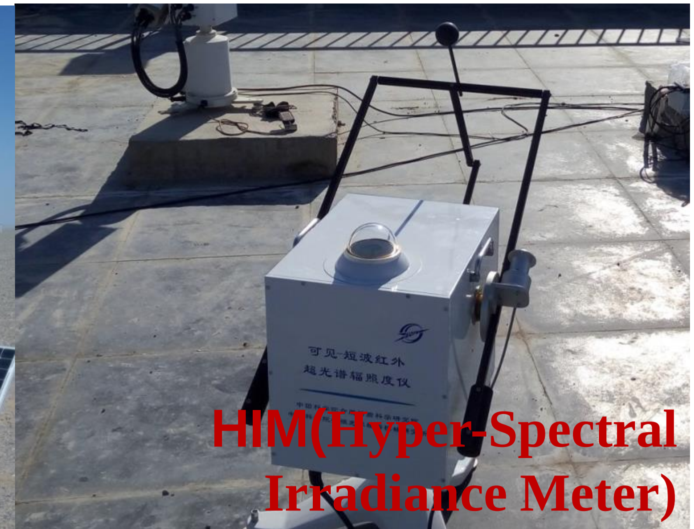
tent to house



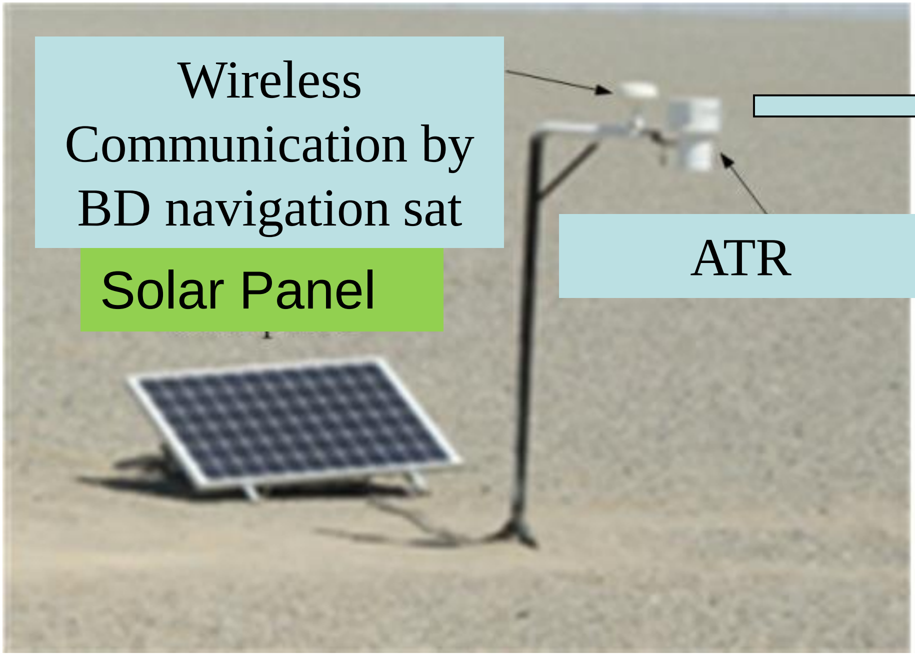
View from a 30m high tower crane

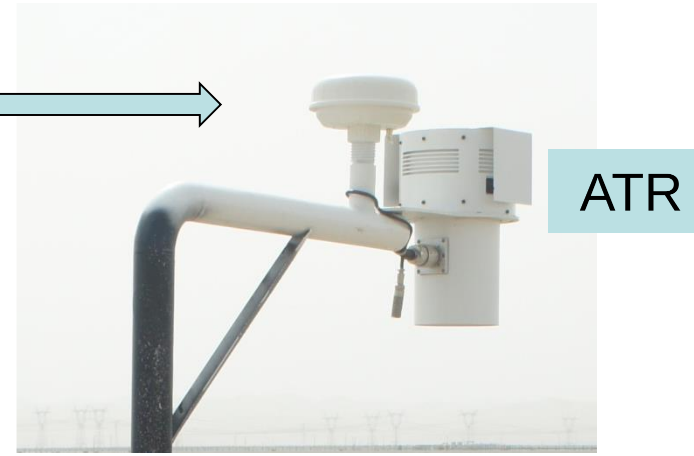
Introduction of automatic observation instruments on Dunhuang site





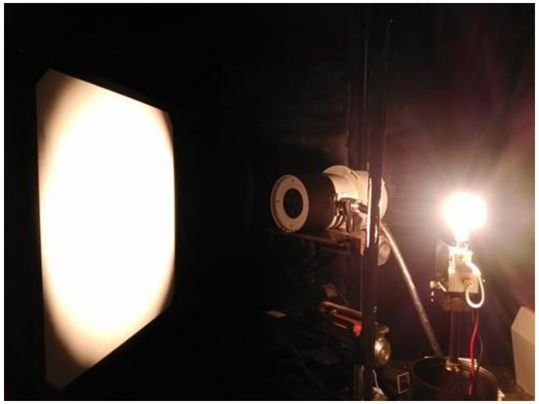
Automated Test-site Radiometer(ATR)





Automated Test site Radiometer(ATR)

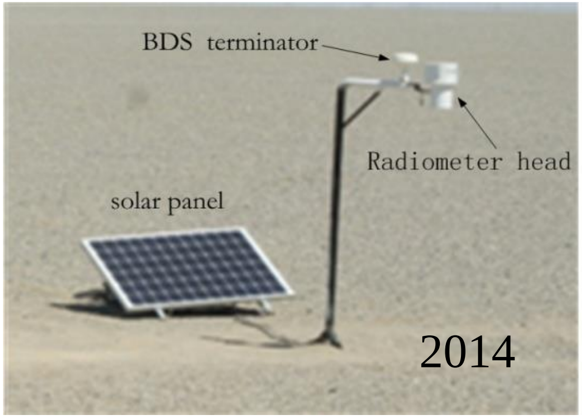
Center wavelength	405, 450, 525, 610, 700, 808, 980, 1540nm
FWHM bandwidth	20nm~40nm
Field of view	10°
Operating temperature	-40℃~65℃
Control temperature	25℃±5℃
Communication	RDSS/GPRS

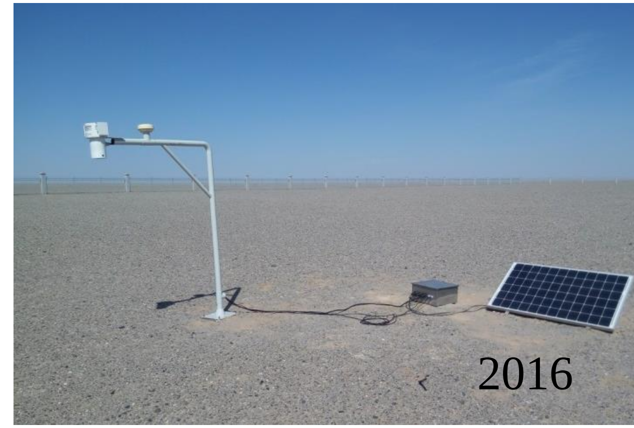


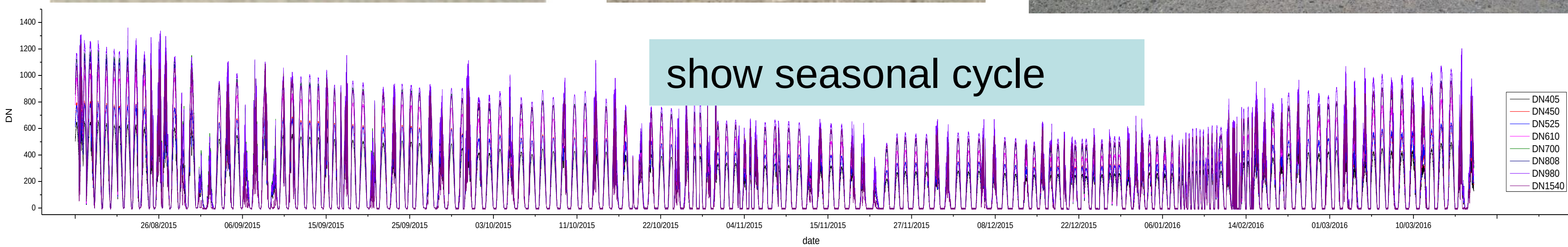
A standard of spectral irradiance from a standard lamp illuminates on a reference panel located 500mm from bulb.

The differences of Lab calibration result from 2014~2016

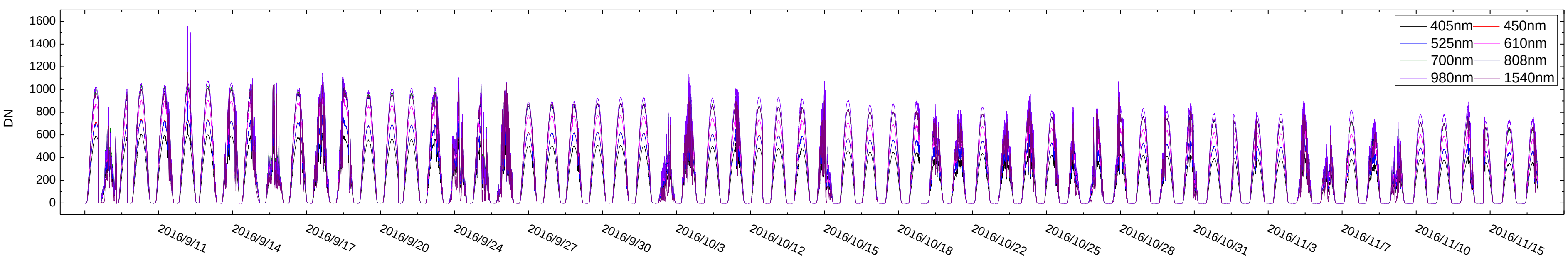
Wavelength /nm	**DN(2014)**	**DN(2015)**	**DN(2016)**	**Relative different （%）**	
				2015/2016	**2014/2016**
405	95	95	95	**0**	**0**
450	136	137.6	139.00	**1.01**	**2.15**
525	227	229.8	228.00	**-0.79**	**0.43**
610	400.17	413	398.00	**-3.77**	**-0.54**
700	742	735	723.14	**-1.64**	**-2.60**
808	1041.06	1014.8	1033.08	**1.77**	**-0.77**
980	1808.10	1737.8	1793.44	**3.10**	**-0.82**
1540	1832.69	1848.2	1860.17	**0.64**	**1.47**







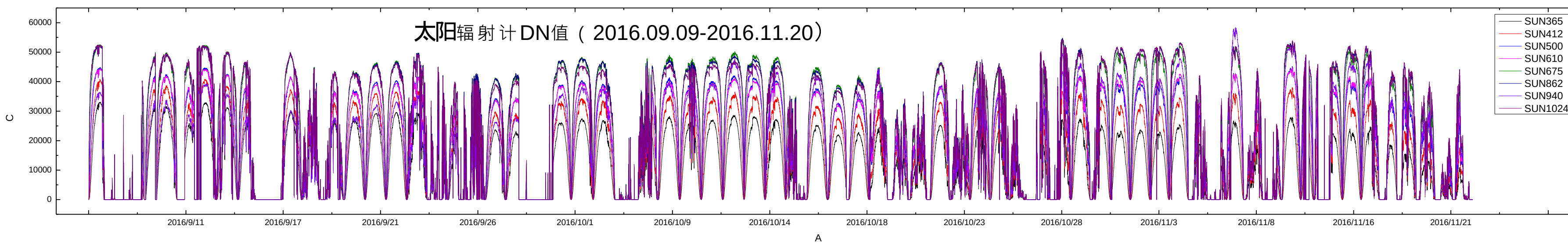
DNs measured by ATR from Aug, 2015 ~ Apr, 2016



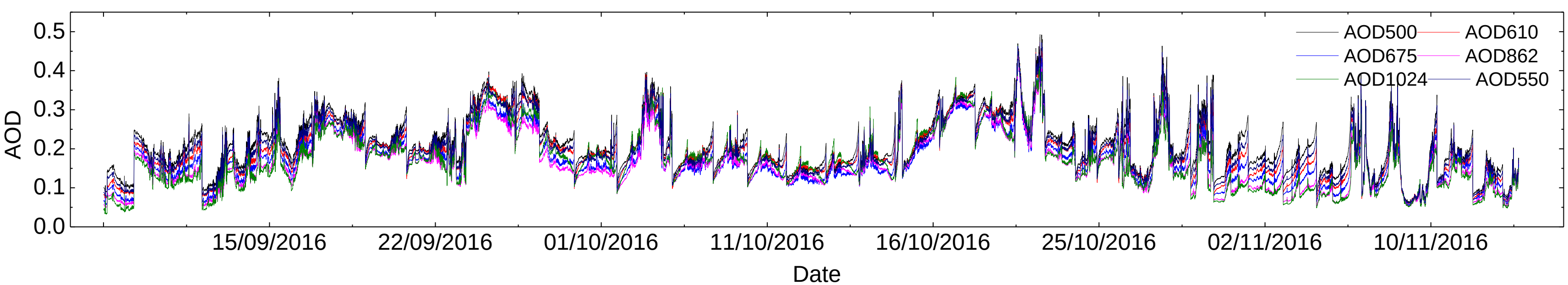
DNs measured by ATR from Sep, 2016 ~ Nov, 2016

Precision Solar Radiometer-PSR

Center wavelength(nm)	365，410，500，610，670，860，940，1024nm
FWHM bandwidth	10nm(5nm at 365nm)
FOV	2°
Tracking precision	±0.1°
Tem control	30℃±0.2℃

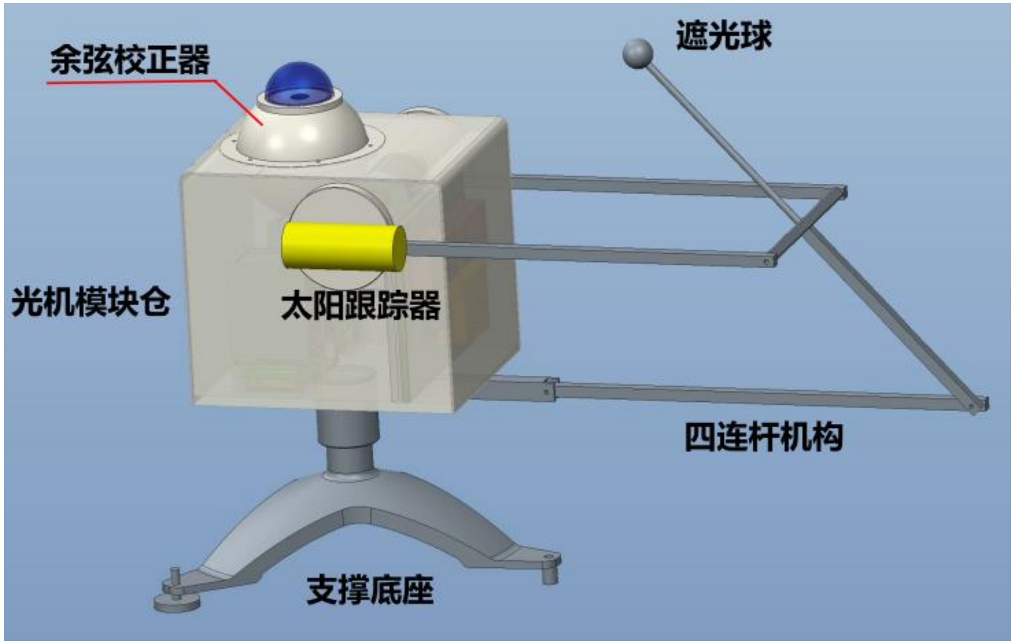


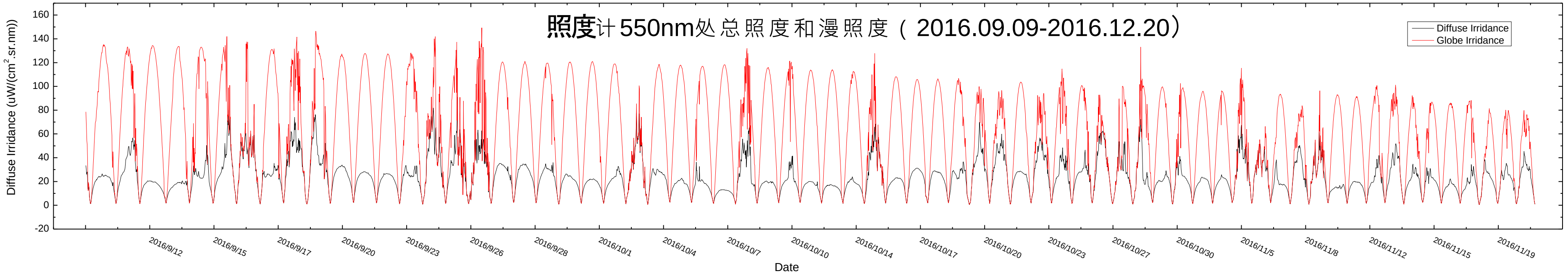
DNs measured by PSR from Sep to Nov, 2016



AOD obtained by PSR from Sep to Nov, 2016

VNIR Hyper-spectral irradiance Meter-HIM



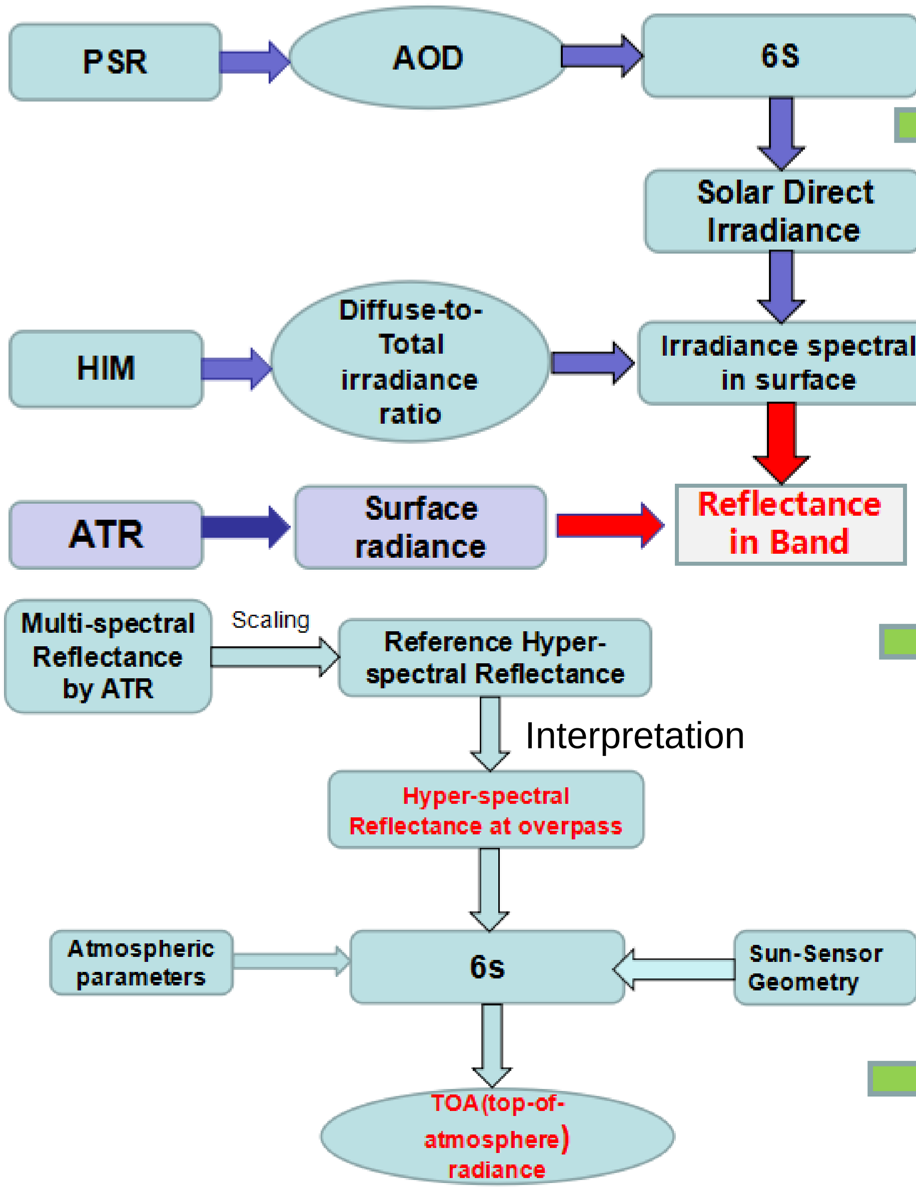


Total irradiance and diffuse irradiance in 550nm measured by HIM from Sep to Nov, 2016

Specification of HIM

Spectral Range	400~2400nm
Spectral Resolution	≤4nm（@400~950nm） ≤15nm（@950~1700nm） ≤20nm（@1700~2400nm）
Signal-Noise Ratio	SNR≥600@600nm SNR≥200@1500nm SNR≥100 @2100nm（M=2）
Control Temperature	-10±0.1℃（SWIR1） -20±0.1℃（SWIR2）
Operating Temperature	-40℃~ 65℃
Tracking Accuracy	±0.1°
Uncertainty of Measurement	400~950nm, <3%(@600nm); 1000~1700nm, <4%(@1500nm); 1700~2500nm, <5%(@2100nm)
Power requirement	220VAC , 24VDC
Instrument dimension	380×280×400mm

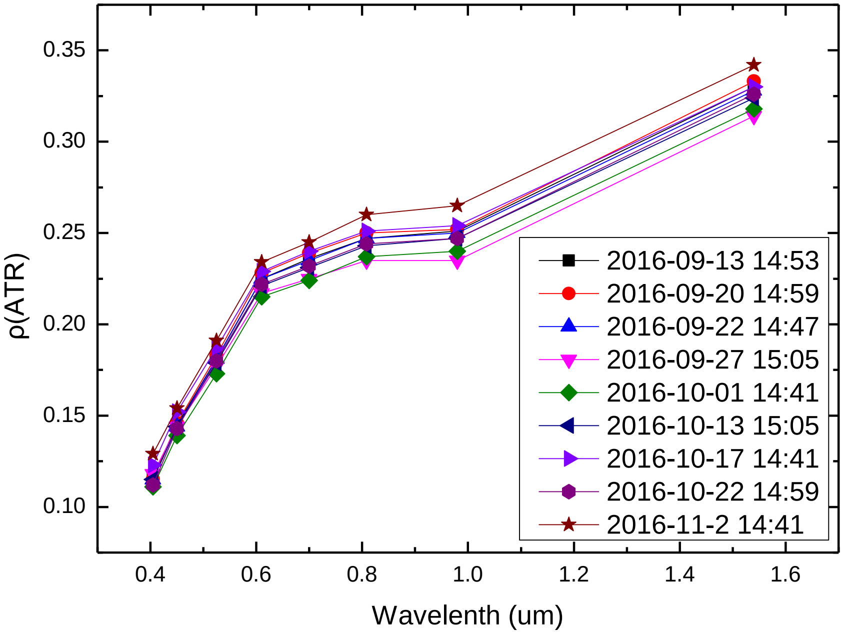
Radiometric calibration method based on automatic observation instruments on Dunhuang site

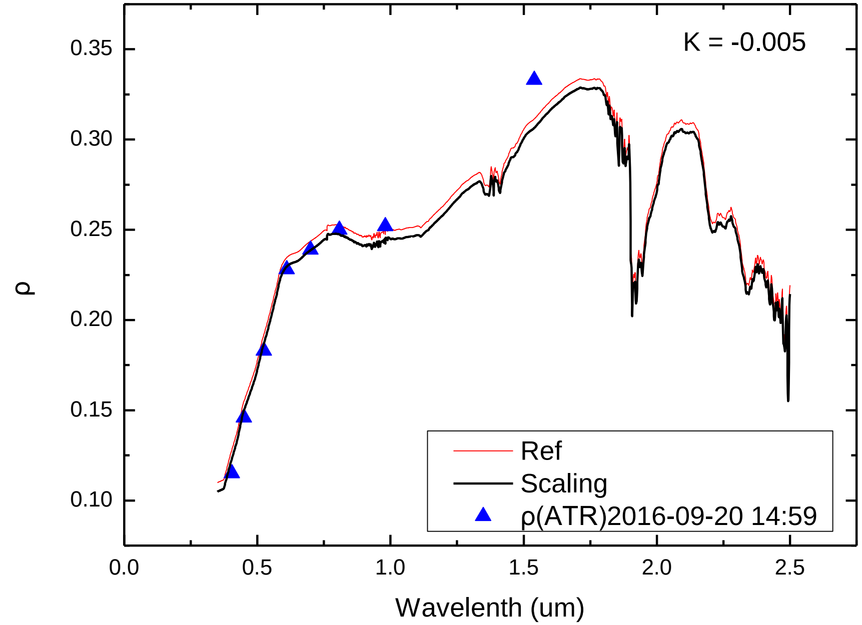


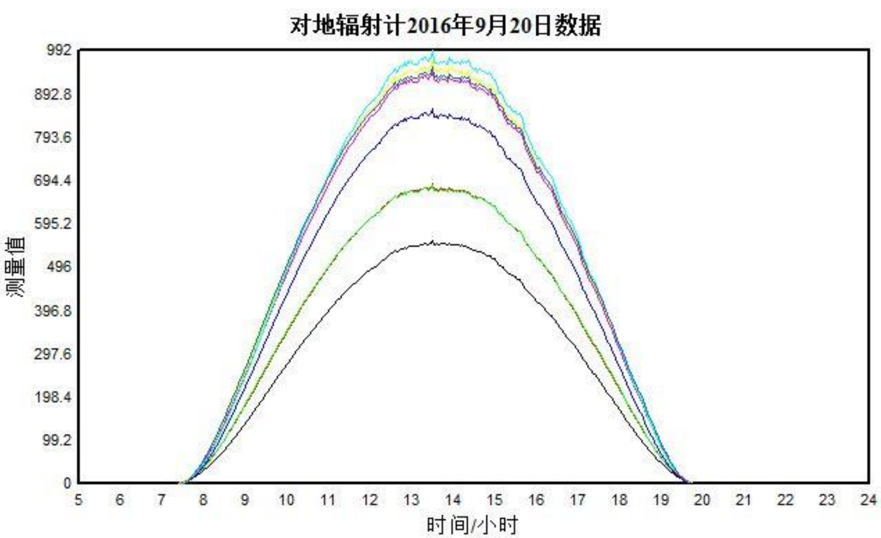
The surface Reflectance in band by PSR, NIM and ATR instruments

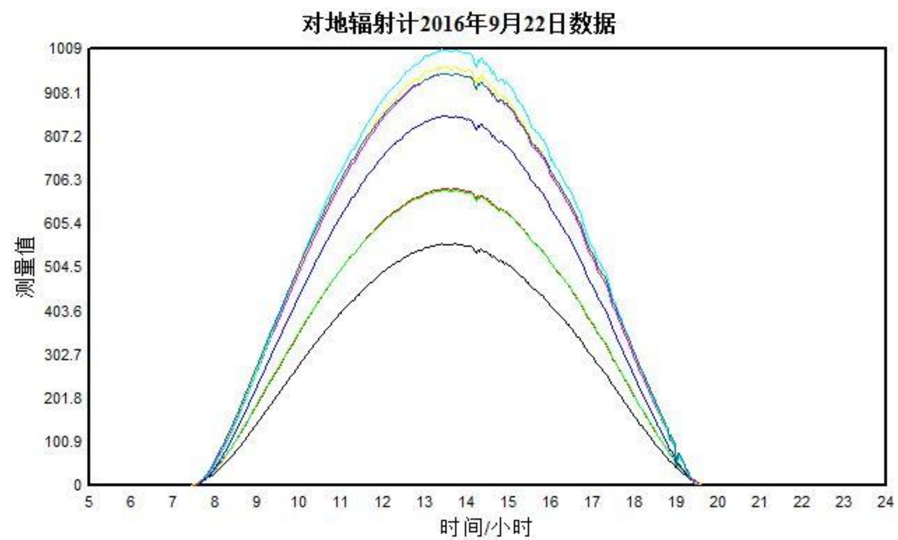
The surface Reflectance in band is scalled to Hyper-spectral reflectance at the satellite overpass time by a priori hyper-spectral reflectance(reference reflectance)

Calculation the TOA radiance and comparision to the satellite observation


ρ(ATR)
Wavelenth (um)
2016-09-13 14:53
2016-09-20 14:59
2016-09-22 14:47
2016-09-27 15:05
2016-10-01 14:41
2016-10-13 15:05
2016-10-17 14:41
2016-10-22 14:59
2016-11-2 14:41


K = -0.005
ρ
Wavelenth (um)
Ref
Scaling
ρ(ATR)2016-09-20 14:59


对地辐射计2016年9月20日数据
测量值
时间/小时


对地辐射计2016年9月22日数据
测量值
时间/小时

Differences(%) between calculation and MODIS

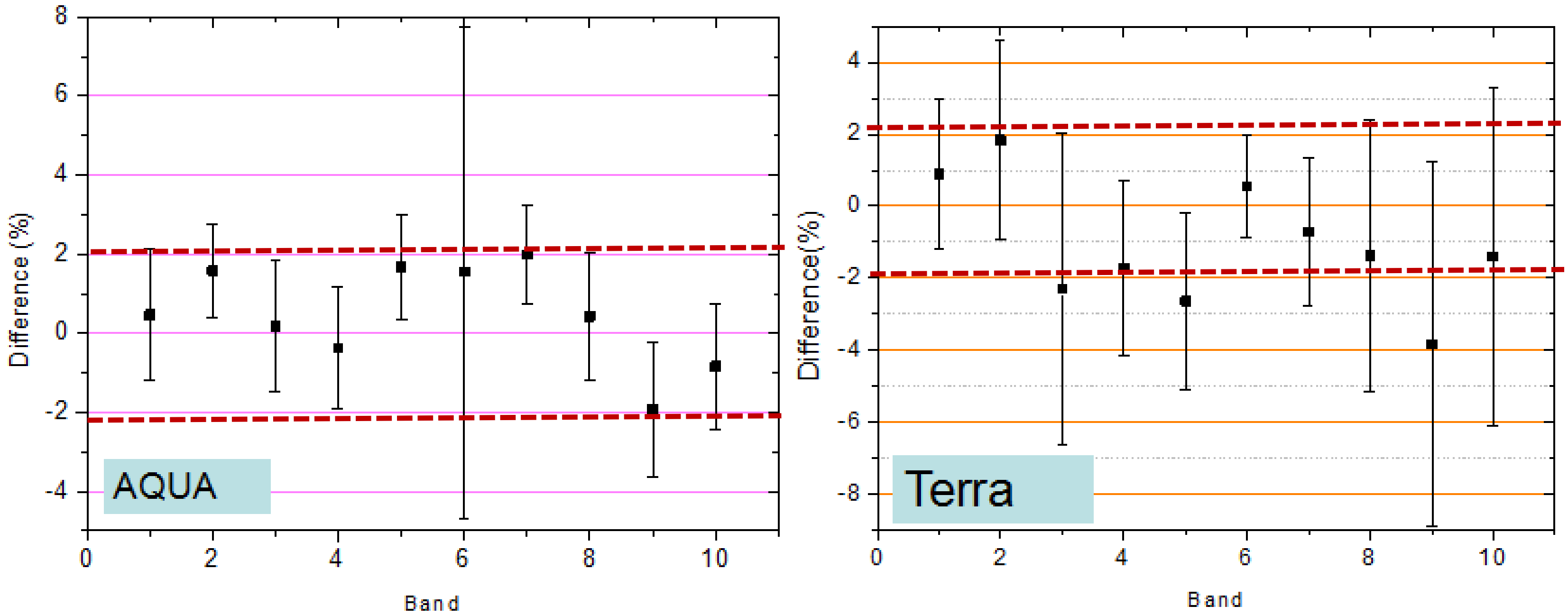
Terra

Band	2016/9/12	2016/9/21	2016/10/12	2016/11/4	2016/11/15
1	-0.70	1.99	-1.91	3.08	2.05
2	0.61	2.28	-2.17	3.31	5.17
3	-4.31	-0.64	-4.91	4.52	-6.22
4	-3.29	-0.07	-4.34	1.54	-2.41
5	-3.39	-0.03	-5.43	-4.26	-0.08
6	-1.04	2.49	-0.21	1.51	15.38
7	-2.63	2.00	-2.91	-0.06	23.95
8	-4.02	-0.48	-2.56	4.77	-4.59
9	-6.34	-2.34	-6.54	4.38	-8.35
10	-3.84	-0.65	-3.59	6.48	-5.39

The value more than 10% is marked with red.
The value more than 5% is marked with blue.

Aqua

Bandwidth (nm)	2016/9/13	2016/9/20	2016/9/22	2016/9/27	2016/10/13	2016/10/17	2016/11/2
620 - 670	-0.71	0.94	-1.51	0.86	1.46	3.21	-1.00
841 - 876	1.78	2.75	0.96	1.40	0.56	3.45	0.12
459 - 479	-1.20	1.16	-1.38	-0.11	1.90	2.51	-1.53
545 - 565	-1.02	0.39	-2.29	-0.19	0.74	1.89	-2.08
1230 - 1250	0.68	2.45	0.59	1.21	1.39	4.30	0.97
1628 - 1652	1.79	-11.81	2.86	3.13	2.91	8.02	3.94
2105 - 2155	-0.06	2.14	0.93	2.11	2.40	3.81	2.55
405 - 420	-1.45	1.55	-0.97	0.10	2.00	2.51	-0.76
438 - 448	-4.16	-0.93	-3.61	-1.89	-0.18	0.21	-2.99
483 - 493	-2.44	-0.11	-2.57	-1.25	0.90	1.42	-1.80



Average and standard deviation of relative difference(1σ for uncertainty)

Conclusions:

- **Automatic observation radiometric calibration can improve apparently the calibration frequency up to 2~3 times per month.**
- **By using the AQUA/MODIS as radiation benchmark, the results show that the mean bias is among 2% for most bands and with uncertainty less than2%(1% except Aqua band6)**
- **Some abnormal observation will greatly effect the results.**

Discussions

◆For Instruments:

- The intruments' parameters, including SNR/linearity/Straylight/longterm repeatability variation/dark current variation of automatic instruments have been tested in the laboratory, but re-tested by the RadCalNet are welcomed.
- We hope the RadCalNet can also help to do the absolute radiometric calibration for automatic instruments, that could be tracable from NPL or NIST radiometric standard.
- Eventhough the automatic instruments have been tested on the field for almost two years, the long-term stability and robustness should be investigated.

◆For Data Processing:

- Automatic data quality control is needed.
- The methods how to get the surface reflectance should be evaluated(such as seasonal cycle of reference surface reflectance)
- BRDF model is essential for low-resolution sensor calibration.

Thanks for your attention!