WGCV Infrared and Visible Optical Sensors(IVOS) meeting

CONSISTENT TRANSFER RADIOMETRIC CALIBRATION TECHNOLOGY & FIELD CAMPAIGN VALIDATION

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Outlines

1. Objectives and concept

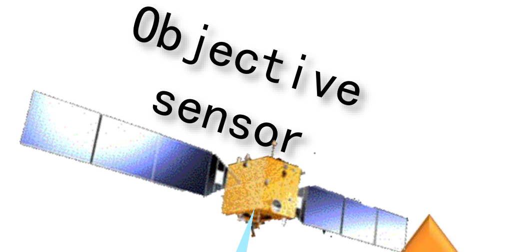
2. Composition of the system

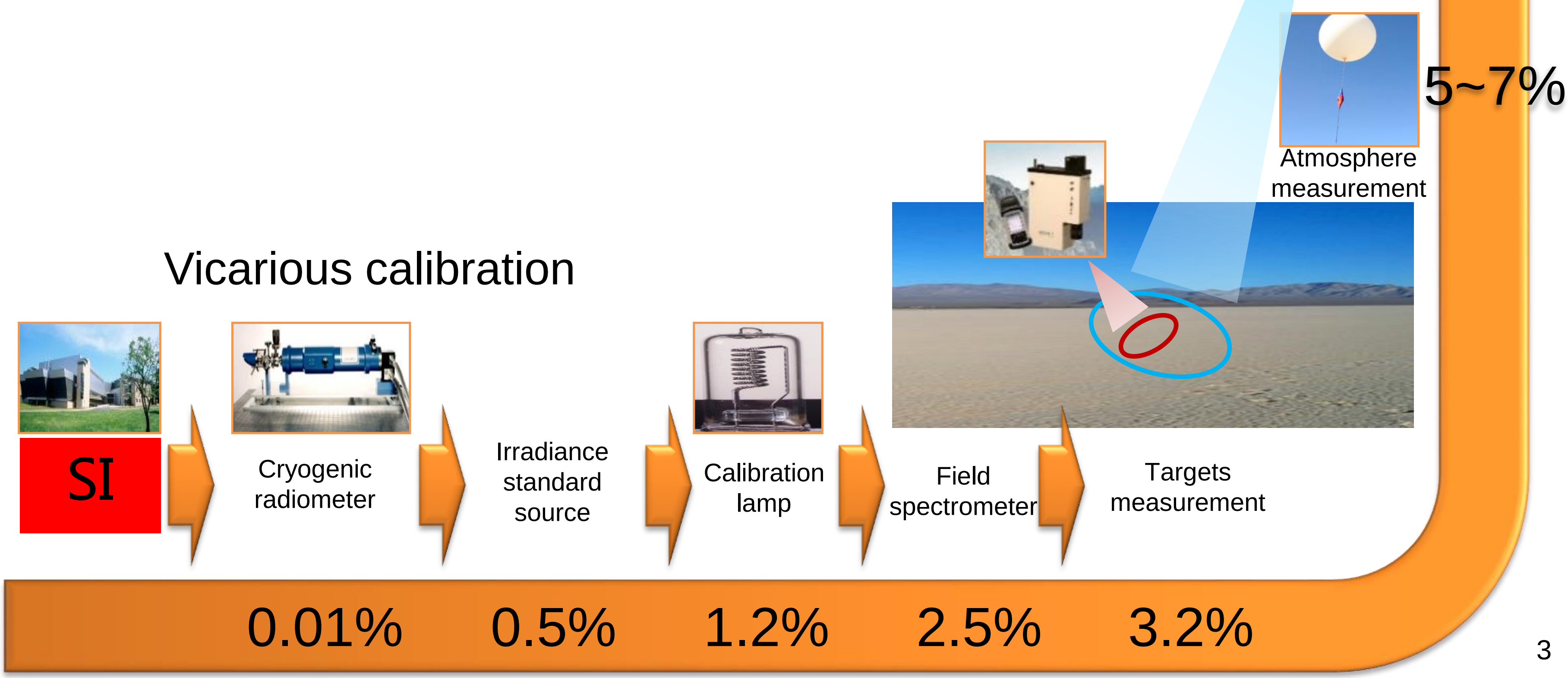
3. Flight campaign and preliminary results

4. Future plans

1. Initiative and concept

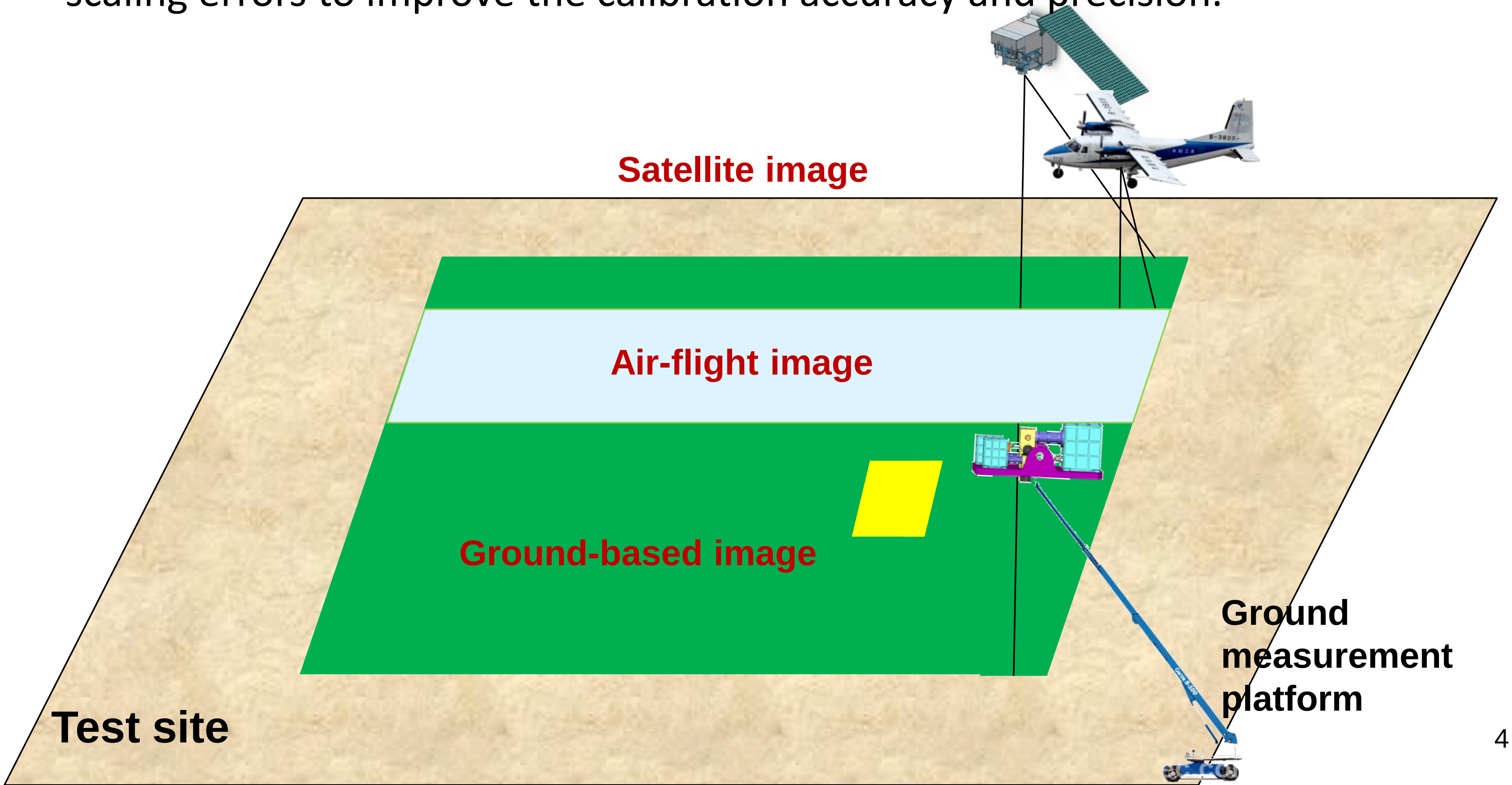
In vicarious calibration, it is difficult to decrease the uncertainties introduced by heterogeneity of surface, variation of atmosphere, and calculation of atmospheric radiative transfer.



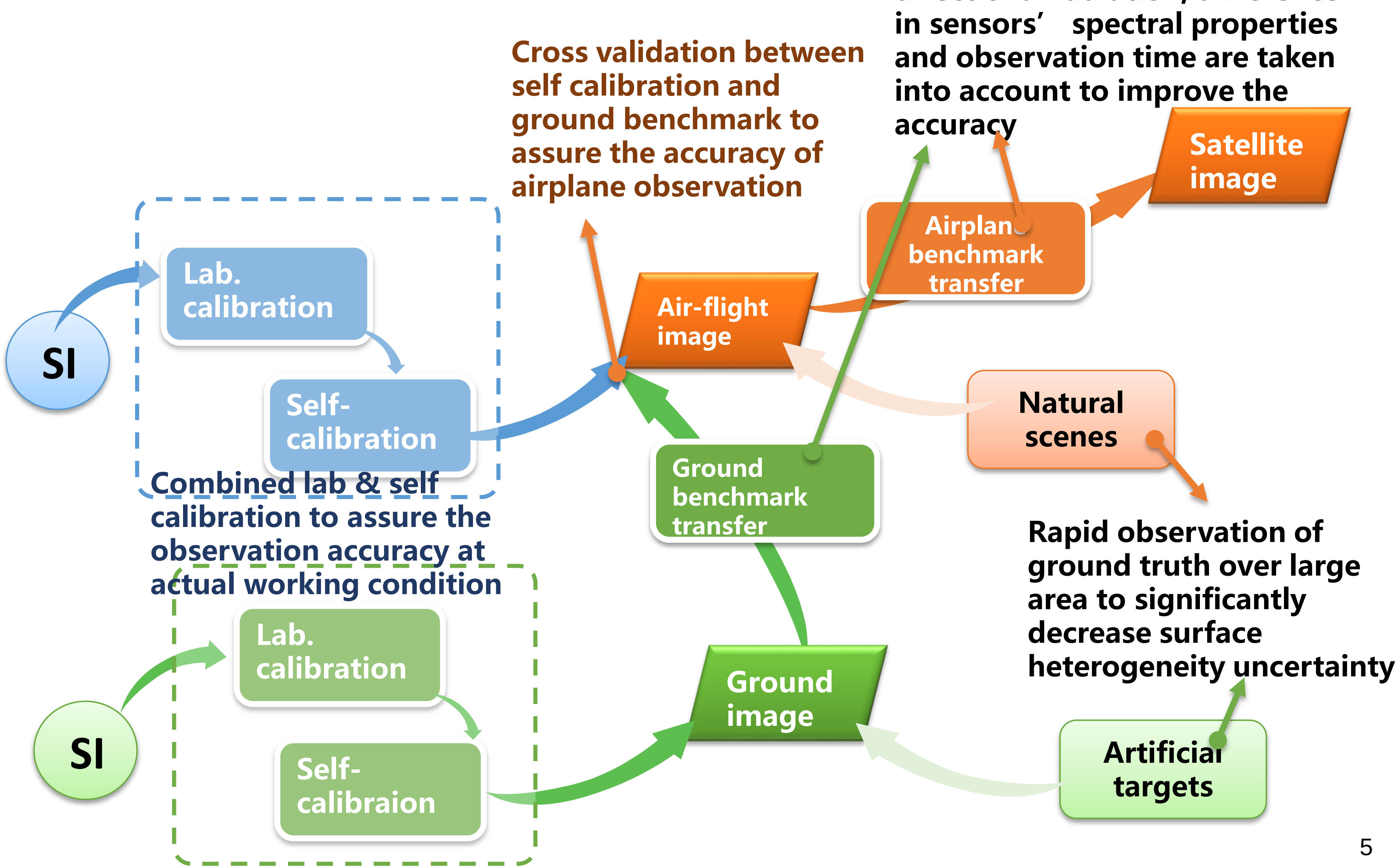


1. Objectives and concept

- Observe the same targets at satellite, airplane and ground platforms synchronously to obtain the measurement benchmark, employing the ground-based and airborne spectral imager that traced to SI.
- Then the benchmark (also be ground truth at pixel scale) can be transferred firstly to airborne imager, then to satellite sensor without introducing large scaling errors to improve the calibration accuracy and precision.



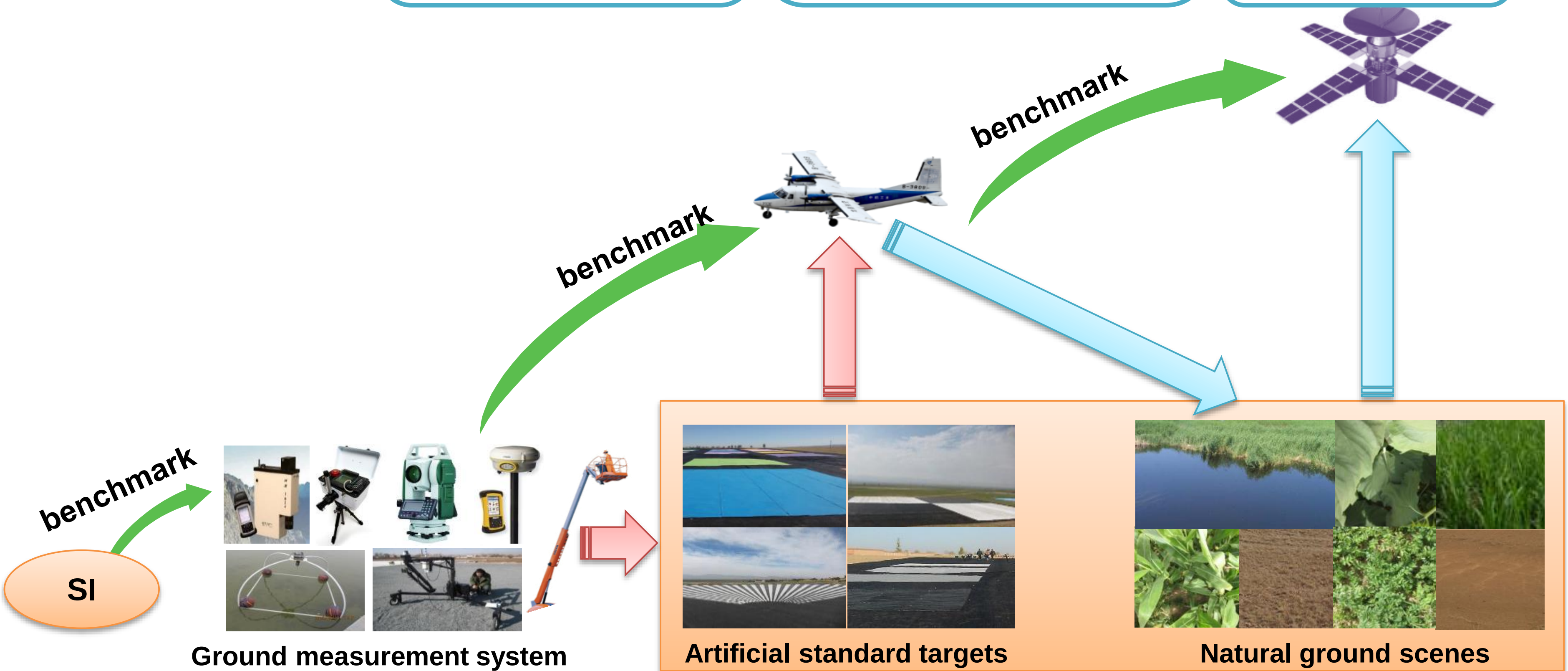
Tow Chains


Surface BRDF, atmospheric directional radiation, difference in sensors' spectral properties and observation time are taken into account to improve the accuracy
Cross validation between self calibration and ground benchmark to assure the accuracy of airplane observation
Satellite image
Airplane benchmark transfer
Air-flight image
Lab. calibration
Self-calibration
SI
Natural scenes
Ground benchmark transfer
Combined lab & self calibration to assure the observation accuracy at actual working condition
Rapid observation of ground truth over large area to significantly decrease surface heterogeneity uncertainty
Lab. calibration
Self-calibraion
SI
Ground image
Artificial targets

2. Composition

3 Key components

- Different types of artificial targets and natural scenes
- Standard ground instrument and airborne payloads traced to SI
- Benchmark transfer method

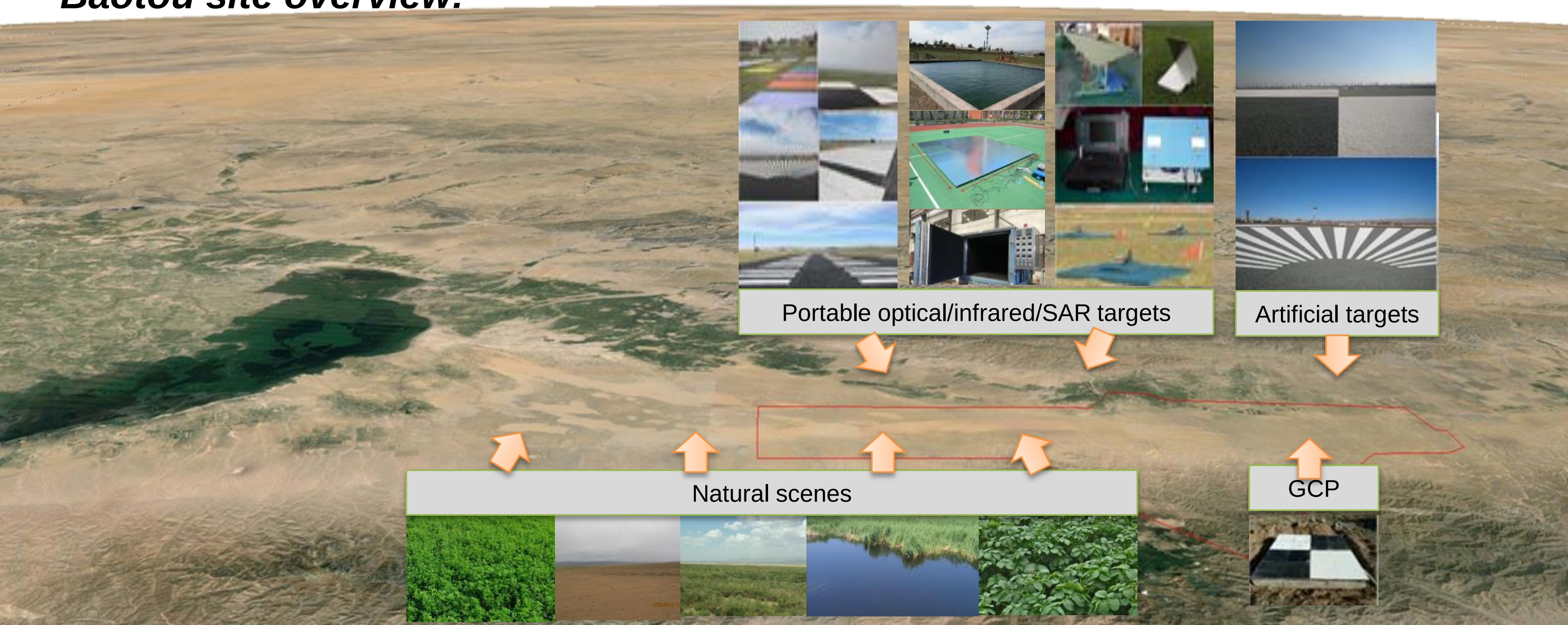


2. Composition

2.1 Different types of artificial targets and natural scenes

- Located in the Inner Mongolia, China; 50km away from the Baotou city.
- A flat area of approximately 300km^2, about 1270m above sea level.
- Land covers: Sand, bare soil, grass, lake, various crops .
- Targets: Artificial permanent targets and portable targets

Baotou site overview:



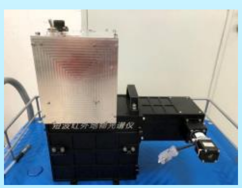
2. Composition

2.2 Standard ground-based and airborne hyperspectral imager

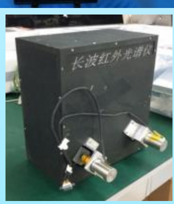
In order to obtain the “truth” value of ground scenes and targets, ground-based and airborne hyperspectral imagers which have the consistent design parameters with self-calibrators are developed by SITP, CAS.

Ground hyperspectral imager

VNIR
400-1050nm
650 channels
0.002m@1m



SWIR
1000-2500nm
300 channels
0.002m@1m



LWIR
8-12.5μm
150 channels
0.01m@1m

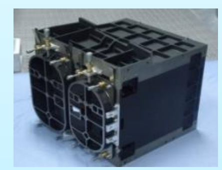
Covering the same spectral range

More channels and higher resolution for ground imagers

Self-calibration units

Lab calibration traced to SI

Airborne hyperspectral imager



VNIR
400-1050nm
300 channels
0.5m@1km

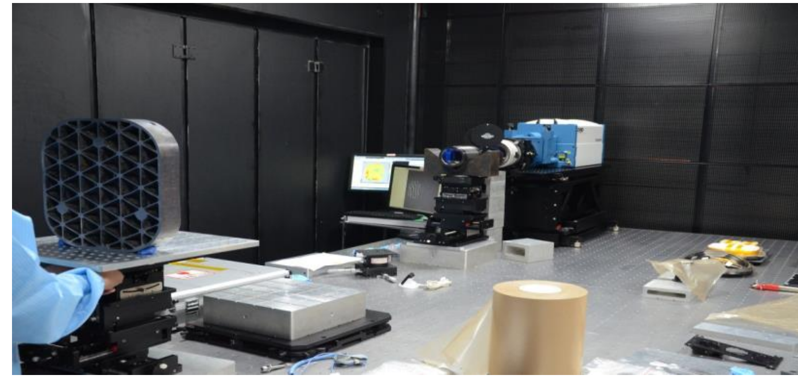
SWIR
1000-2500nm
170 channels
0.5m@1km

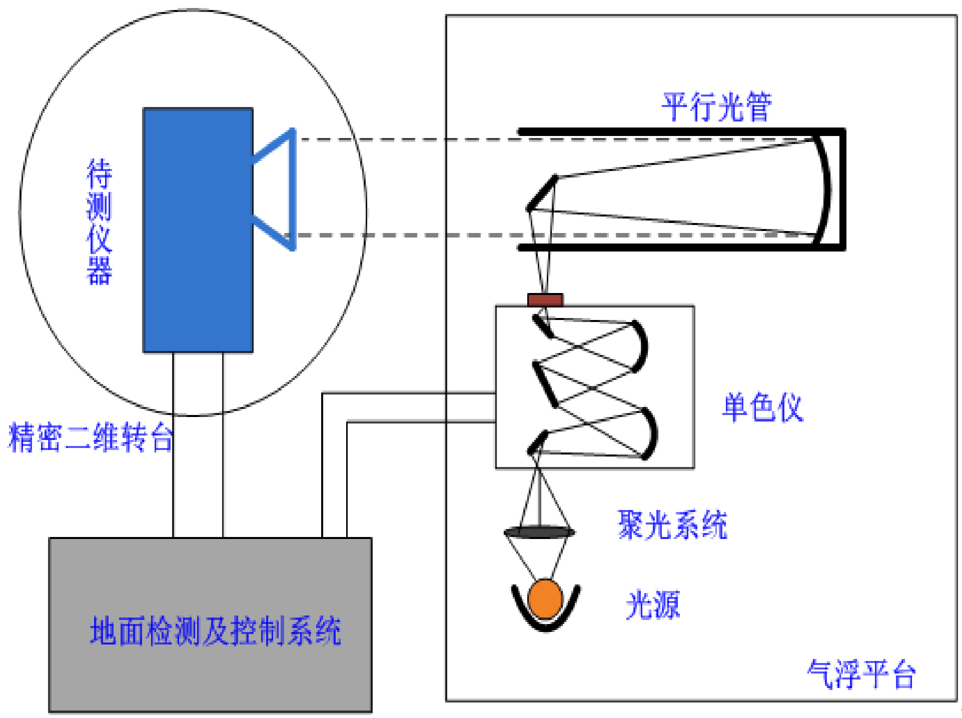
LWIR
8-12.5μm
75 channels
0.5m@1km

2. Composition

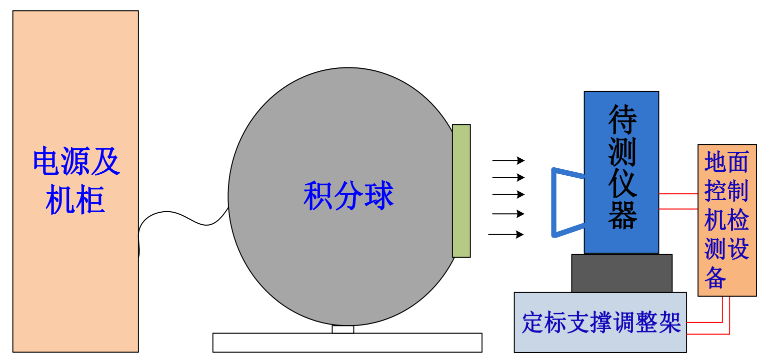
2.2 Standard ground-based and airborne hyperspectral imager

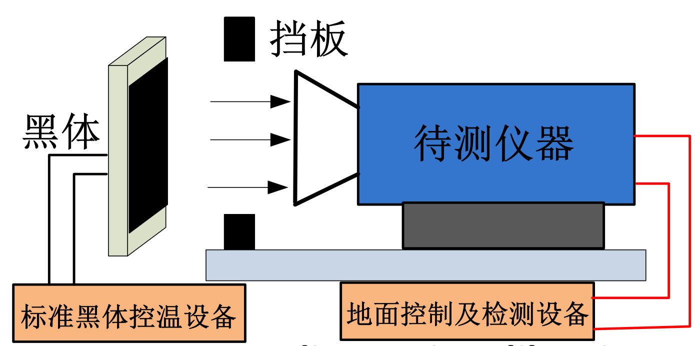
Performance tests in lab





Spectral calibration





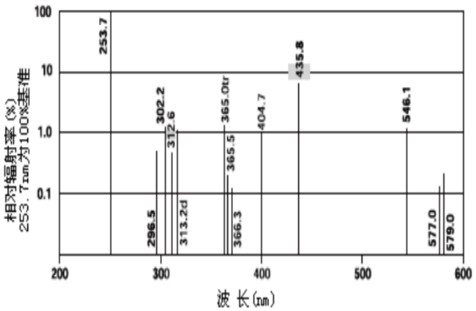
Radiometric calibration

2. Composition

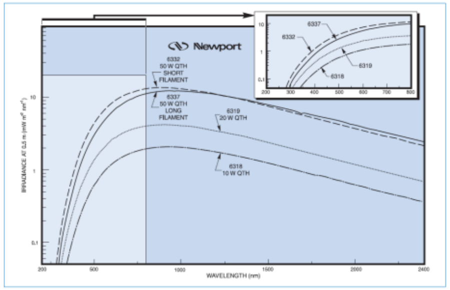
2.2 Standard ground-based and airborne hyperspectral imager

Full-FOV, full-aperture and full-light-path self calibrator units are developed.

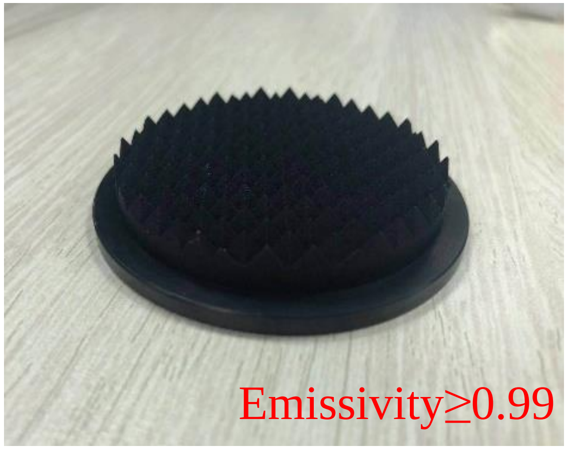
The self calibrators have been compared with laboratory calibrators (an NIST-traceable sphere). The performance at actual working condition have also been tested and estimated.



Pen type low pressure mercury lamp and characteristic spectral line



QTH lamp and spectral curve



High-emissivity blackbody(BB)

2.2 Standard ground-based and airborne hyperspectral imager

Calibration uncertainties employing self-calibration units for ground imagers

Factors	VNIR	SWIR	LWIR
Uniformity of self-calibrator	1.00%	1.00%	0.1K
Stability	1.0%	1.2%	0.1k
Radiance uncertainty	1.0%	1.0%	0.1K
Transfer uncertainty	0.27%	0.23%	0.2K
Imager stability	0.28%	0.35%	0.1K
Image response linearity	0.21%	0.52%	0.1K
Stray light	0.20%	0.20%	0.05K
Total uncertainty	1.80%	1.98%	0.30K

Calibration uncertainties employing self-calibration units for airborne imagers

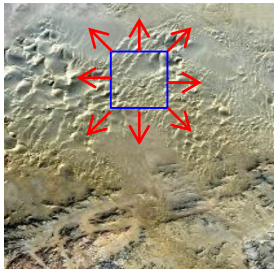
Factors	VNIR	SWIR	LWIR
Uniformity of self-calibrator	2.00%	2.00%	0.2K
Stability	1.0%	1.0%	0.1k
Radiance uncertainty	1.0%	1.0%	0.2K
Transfer uncertainty	0.44%	0.24%	0.3K
Imager stability	0.41%	0.24%	0.2K
Image response linearity	0.49%	0.20%	0.11K
Stray light	≤0.95%	≤1.0%	≤0.1K
Total uncertainty	2.73%	2.48%	0.49K

2.3 Benchmark transfer method

- High accuracy spatial registration between multi-scale remote sensing data

For image registration across satellite data and airborne data which are in different spatial scales, the differential imagery pyramid method is adopted to conduct multiple-feature registration on the identical ground objects. Sub-pixel level (0.1 pixel) of spatial registration accuracy can be reached by this method.

Simulation test indicates that radiance uncertainty due to error of spatial registration is generally no more than 0.5% on relatively uniform scenes like desert and gobi.



Desert
regional non-uniformity 3.6%

Gobi
regional non-uniformity 3.6%

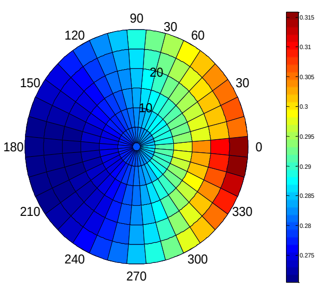
Desert					Gobi				
Reg. err (pix)	Blue	Green	Red	NIR	Reg. err (pix)	Blue	Green	Red	NIR
0.01	0.04%	0.03%	0.03%	0.02%	0.01	0.02%	0.02%	0.03%	0.04%
0.02	0.08%	0.07%	0.05%	0.04%	0.02	0.04%	0.05%	0.06%	0.08%
0.03	0.12%	0.10%	0.07%	0.06%	0.03	0.05%	0.07%	0.09%	0.13%
0.04	0.15%	0.12%	0.09%	0.08%	0.04	0.07%	0.09%	0.12%	0.17%
0.05	0.19%	0.15%	0.11%	0.10%	0.05	0.09%	0.12%	0.15%	0.21%
0.1	**0.34%**	**0.27%**	**0.21%**	**0.18%**	0.1	0.19%	0.23%	0.30%	0.42%
0.15	0.49%	0.39%	0.30%	0.27%	0.15	0.26%	0.33%	0.43%	0.58%
0.2	0.59%	0.47%	0.37%	0.36%	0.2	0.33%	0.41%	0.53%	0.72%
0.25	0.68%	0.55%	0.45%	0.43%	0.25	0.40%	0.48%	0.62%	0.86%

2.3 Benchmark transfer method

- Angular conversion method considering differences on surface reflectance and radiative transfer path

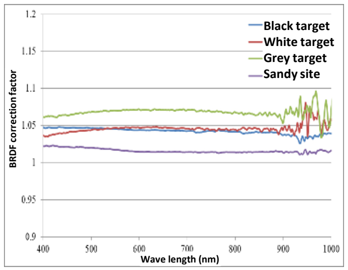
The angular conversion method corrects surface reflectance difference and atmospheric radiative transfer path difference caused by different viewing geometry between airborne and spaceborne data.
Under normal conditions (sand surface, AOD 0.3), the angular conversion accuracy within 15° can be better than 2%.

Surface characteristics

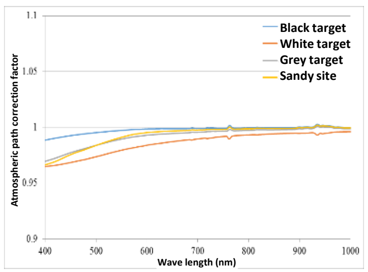


- AOT
- WVC
- Atm. profile
- …

Angular conversion



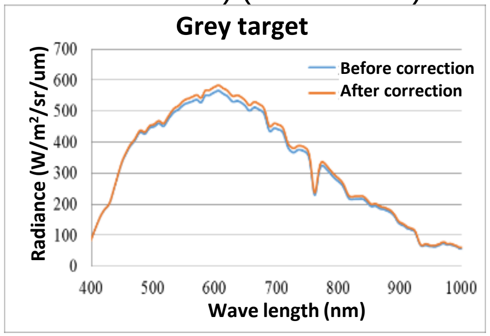
Surface BRF correction



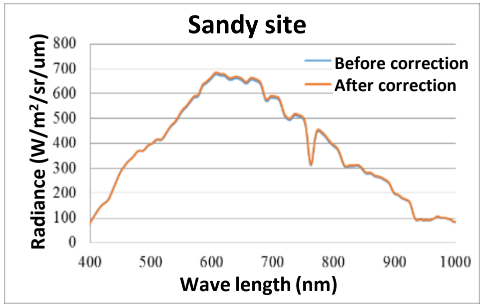
Radiation transfer path correction

Correction result

After angular conversion (airborne vs. SV1-02) (2018.09.23)



Artificial gray target



Sand

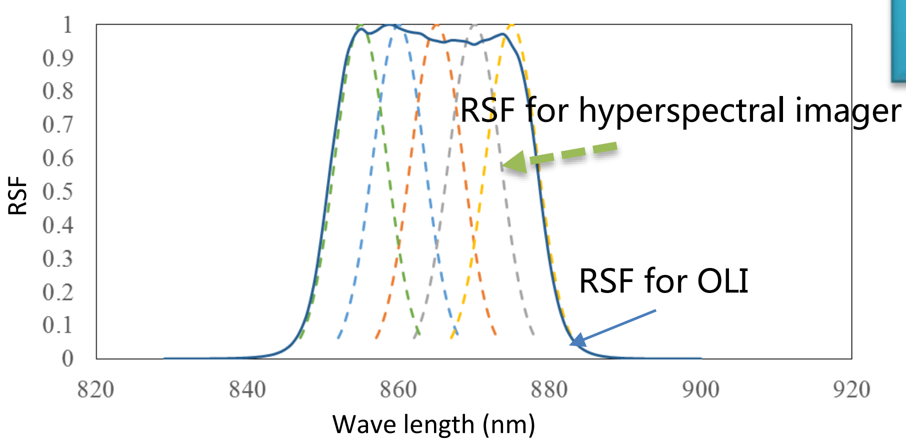
2.3 Benchmark transfer method

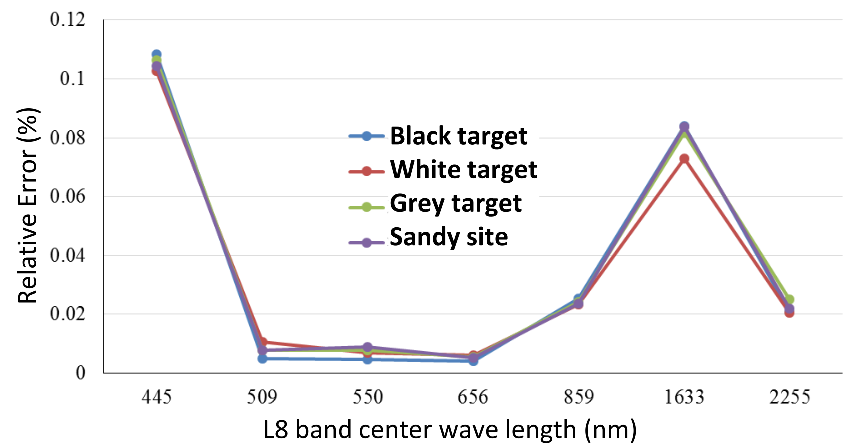
- Spectral matching between satellite sensor and hyperspectral imager

Spectral matching method was validated by comparing in-band simulation directly from MODTRAN and that convolved from hyperspectral simulations under the same atmospheric condition (mid-latitude summer profile).
The error within 0.1% may be introduced for multispectral satellite sensors such as OLI/Landsat 8.

Convolution with spectral response of multichannel sensor

$$\rho_i^e = \frac{\int_{\lambda_1}^{\lambda_2} S(\lambda) * R(\lambda) \mathrm{d}\lambda}{\int_{\lambda_1}^{\lambda_2} R(\lambda) \mathrm{d}\lambda}$$



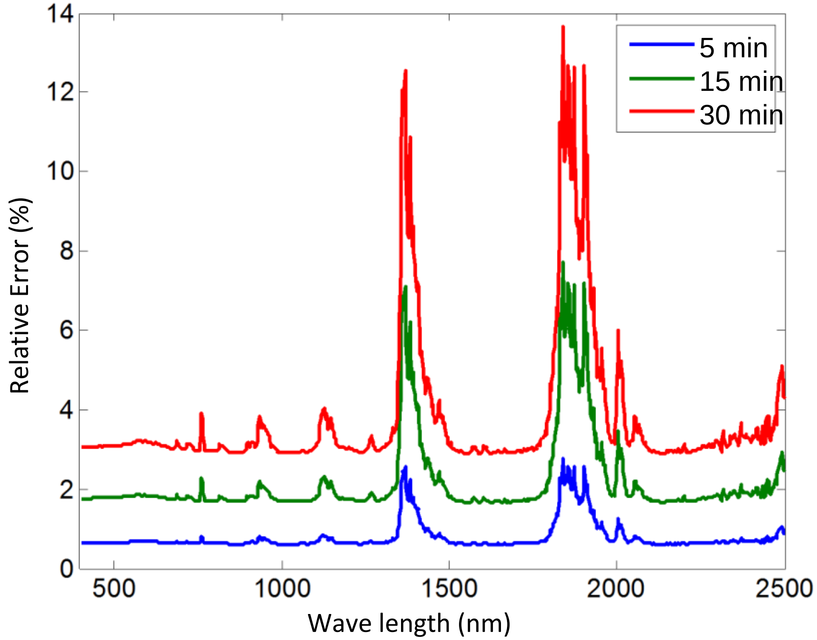


Taking Landsat 8 as example, the errors for all bands are within 0.1%

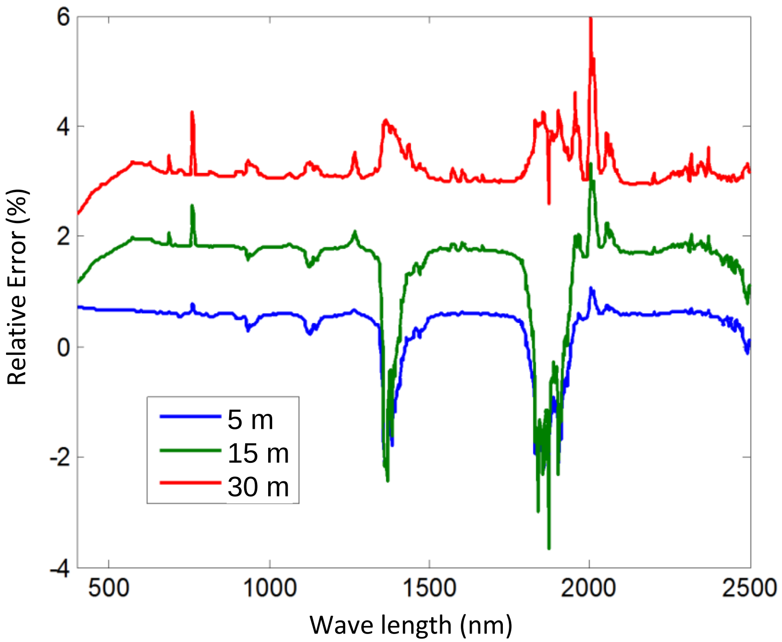
2.3 Benchmark transfer method

- Radiance correction considering acquisition time difference

Using measured atmospheric diurnal variation information, simulation was made to assess influence of observation time discrepancy on the at-sensor radiance. Results indicate when imaging time span is less than 5 minutes, the error due to solar angle and atmospheric condition change is expected to be lower than 0.5% (in atmospheric window).



Error due to solar altitude changes



Error due to solar altitude and atmosphere changes

2. Composition

2.3 Benchmark transfer method

Transfer calibration model for solar reflected spectral range

To reduce the transfer chains, the radiance observed by hyperspectral imagers is used to estimated TOA radiance directly.

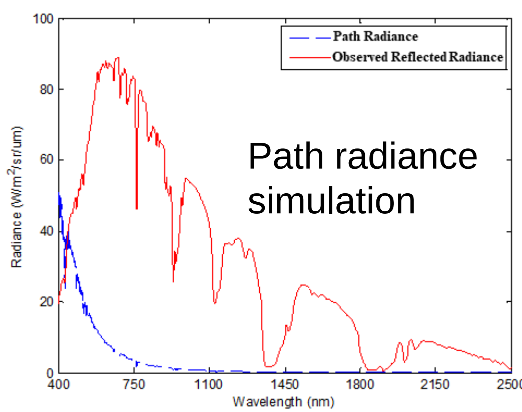
$$L_{TOA} = L_o \cdot \tau + L_p$$

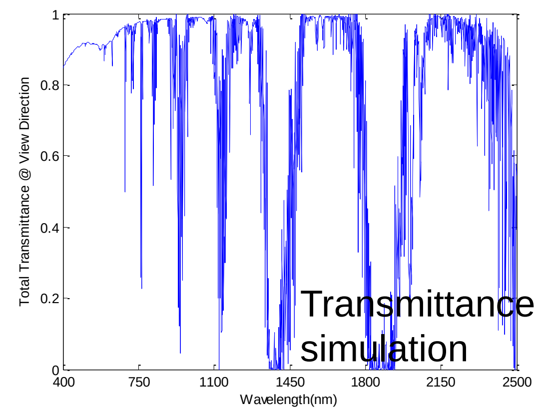
Path radiance

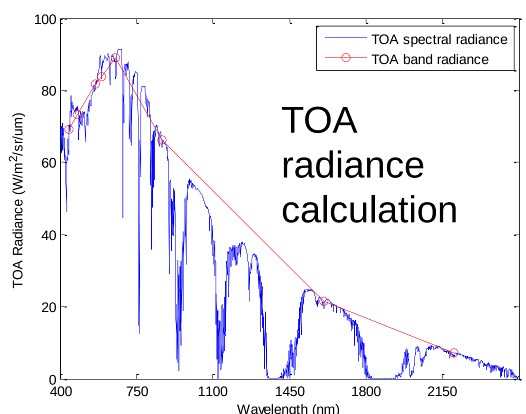
transmittance

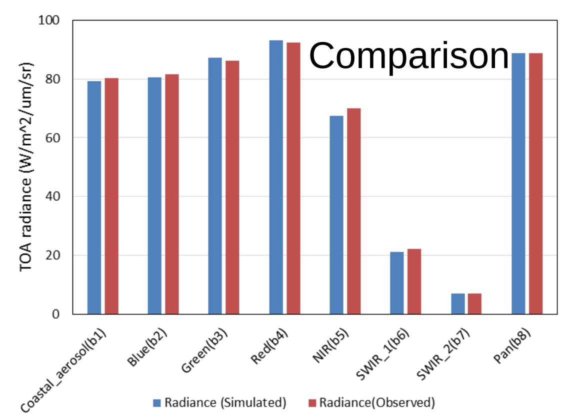
Observed radiance

TOA radiance









2.3 Benchmark transfer method

Transfer calibration model for thermal band

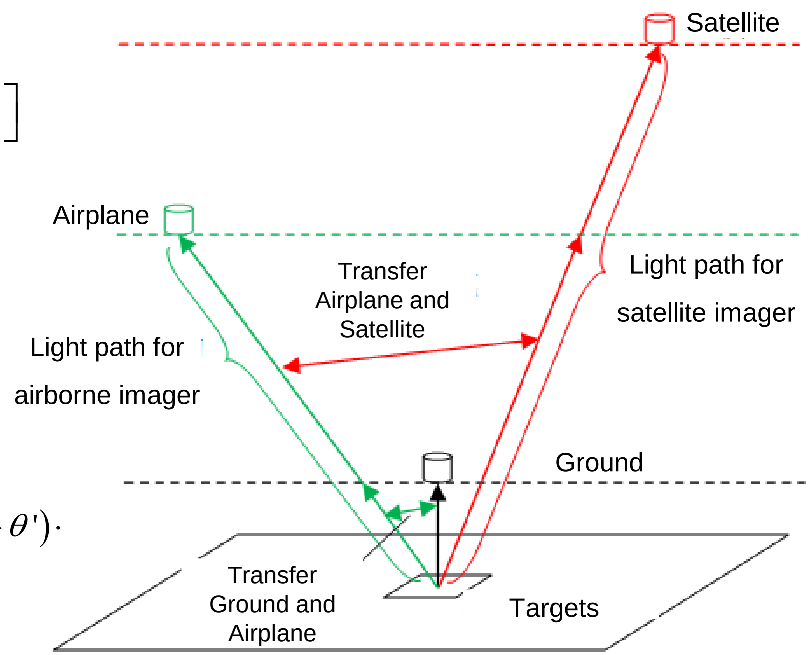
The directional thermal radiation characteristics of surface and atmosphere are considered in atmospheric radiative transfer to describe the effect due to different light paths for ground, airborne and satellite imagers.

- Ground-based imager to airborne imager :

$$L\left(T_{grd\to aero}\right)=\frac{1}{N}\sum_{i=1}^{N}\left[\varepsilon_i\left(\theta_{0i}\to\theta\right)B\left(T_s\right)+\left(1-\varepsilon_i\left(\theta_{0i}\to\theta\right)\right)L_{\downarrow}\right]\cdot\tau_{grd\to aero}\left(\theta\right)+L_{\uparrow grd\to aero}\left(\theta\right)$$

- Airborne imager to satellite imager :

$$L\left(T_{aero\to sat}\right)=\frac{1}{N}\sum_{i=1}^{N}\left\{\left[\varepsilon_i\left(\theta_i\to\theta'\right)B\left(T_s\right)+\left(1-\varepsilon_i\left(\theta_i\to\theta'\right)\right)L_{\downarrow}\right]\cdot\tau_{aero}\left(\theta_i\to\theta'\right)\cdot\tau_{aero\to sat}\left(\theta_i\to\theta'\right)+L_{\uparrow aero}\left(\theta_i\to\theta'\right)+L_{\uparrow aero\to sat}\left(\theta'\right)\right\}$$



2.4 Preliminary uncertainty budget

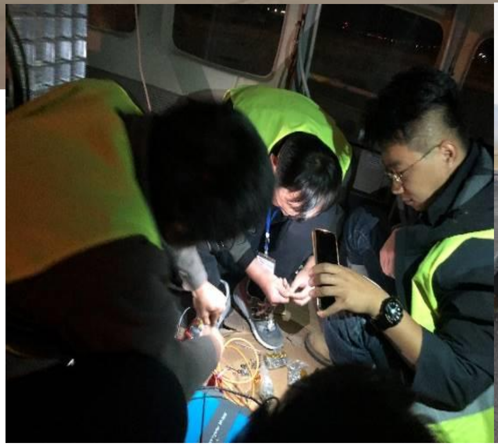
Factors	Errors		Calibration uncertainty	
	VNIR	SWIR	VNIR	SWIR
Stability of imager	1.15%	1.05%	1.15%	1.05%
Self calibrator	2.73	2.48%	2.73%	2.48%
Spatial matching	0.50%		0.50%	0.50%
BRDF	2.00%		2.00%	2.00%
Spectral matching	0.10%		0.10%	0.10%
Temporal difference	<0.5%		0.50%	0.50%
Aerosol optical depth	5.50%		0.11%	0.02%
Water vapour content	10.00%		0.02%	0.02%
Solar irradiance	1.00%		1.00%	1.00%
MODTRAN	2.00%		2.00%	2.00%
Total uncertainty			4.28%	4.09%

Factors	Errors	Calibration uncertainty
Imager observation	0.49K	0.49K
Spatial matching	0.50%	0.18K
Directional thermal radiation	0.3K	0.3K
Temporal difference	--	--
Spectral matching	0.10%	0.04K
Aerosol optical depth	5.50%	0.2K
Water vapour content	10.00%	
Temperature profile	1K	0.22K
MODTRAN	2.00%	0.7K
Total uncertainty		0.97K

3. Flight Campaign

Date： 13th, Sep – 1st, Oct, 2018
Location： Baotou, Inner Mongolia





3. Flight Campaign

● Air-flight system

Airplane： Cessna 208
Payload： VNIR and SWIR hyperspectral imager

Flight height： 2000m (relative altitude)
GSD： 1m(VNIR-SWIR)

● Ground system

Ground platform： Aerial working platform

Payload： VNIR and SWIR hyperspectral imager. The imagers mounted on a two-dimensional turntable

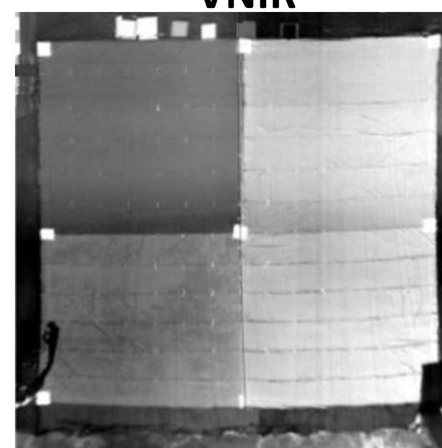
Height： 20m；

GSD： 0.04m(VNIR);

0.04m (SWIR)

Reflectance of targets：50%、40%、30%、20%

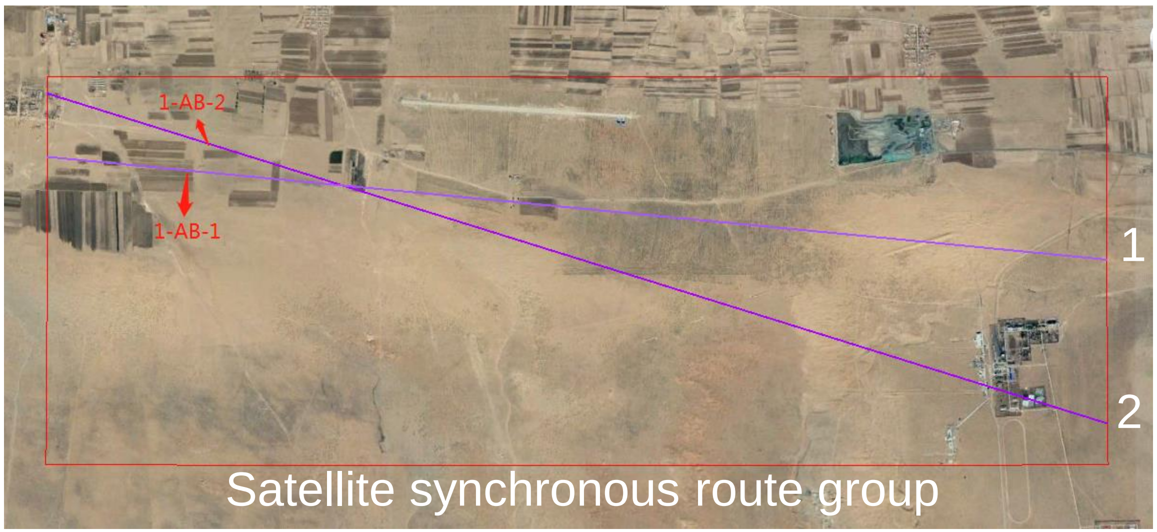
VNIR



SWIR

Flight data acquisition

- 23 Sep: 1 flight for VNIR imager
- 28, 29 Sep: 2 flights for SWIR imager



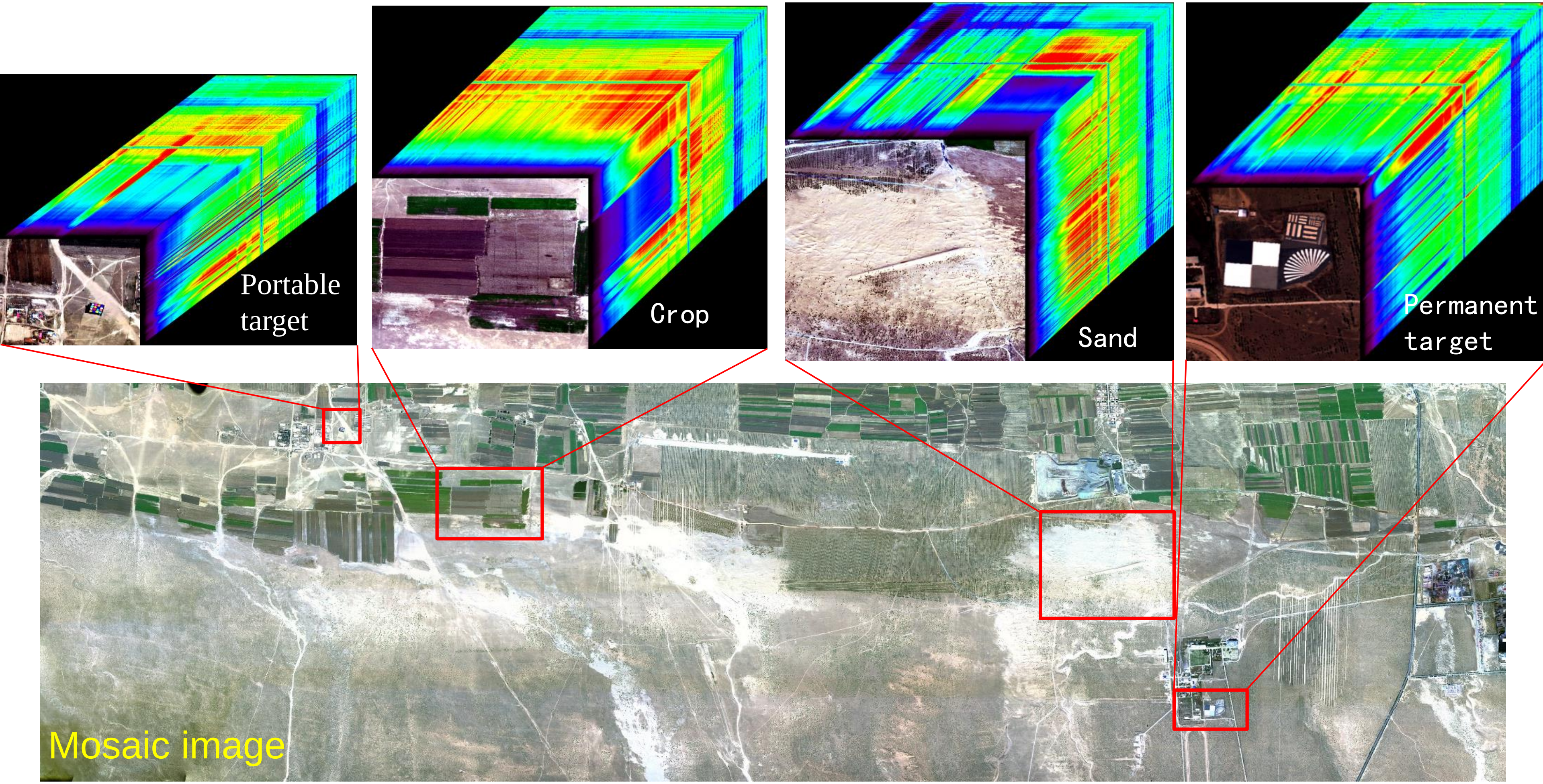
Within 1 hour before and after the satellite overpassing

Other time

3. Flight Campaign

Flight data acquisition

2.2TB hyperspectral data acquired

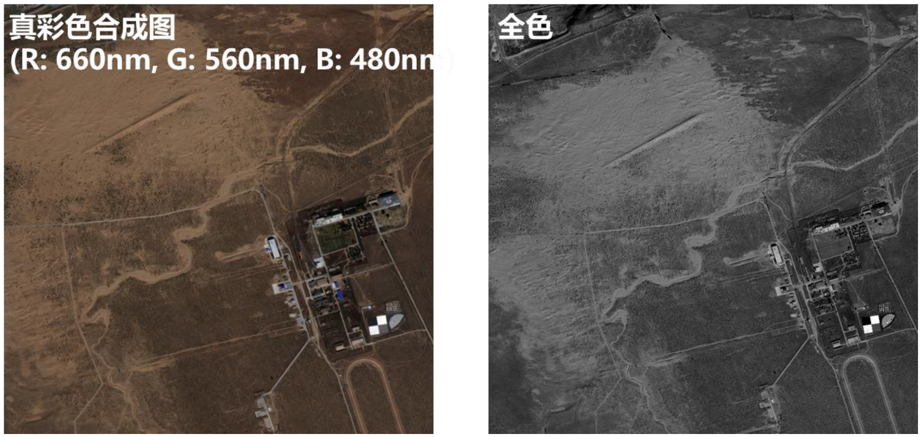


3. Flight Campaign

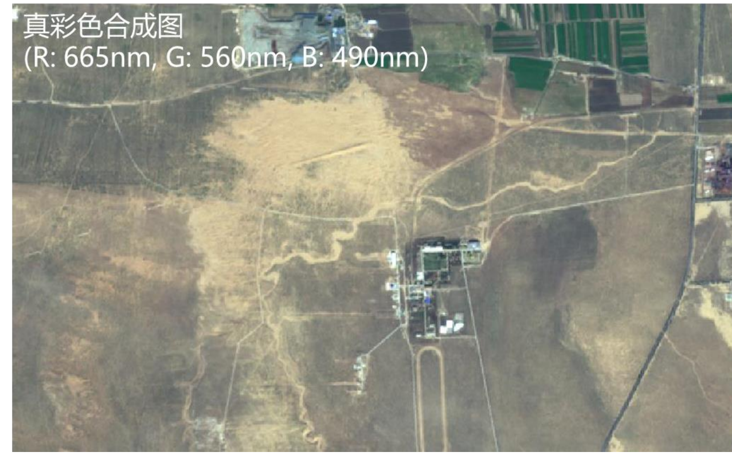
Satellite data acquisition

Satellite	Resolution	Passing time
SV1-03	● Pan 0.5m；MS 2m	20 Sep
GF-2	● Pan 1m；MS 4m	21 Sep
Sentinel-2B	● MS 10m、20m	21 Sep
ZY-1 02C	● Pan 5m；MS 10m	22 Sep
ZY-3	● Pan 2.36m；MS 6m	22 Sep
SV1-01	● Pan 0.5m；MS 2m	22 Sep
OHS2A	● Hyperspectral 10m	22 Sep
SV1-02	● Pan 0.5m；MS 2m	23 Sep
SV1-04	● Pan 0.5m；MS 2m	23 Sep
GF-5	● Hyperspectral 30m	28 Sep
Sentinel-2A	● MS 10m、20m	29 Sep
LandSat 8	● MS 30m	4 Oct

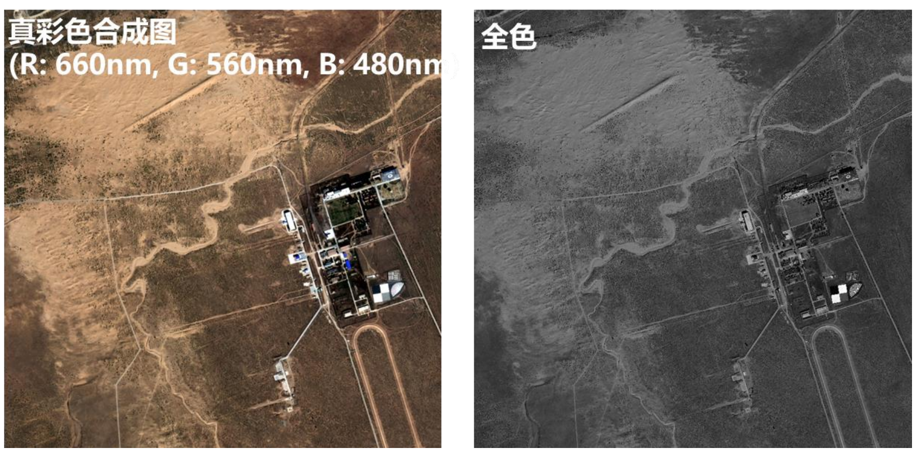
Satellite data acquisition



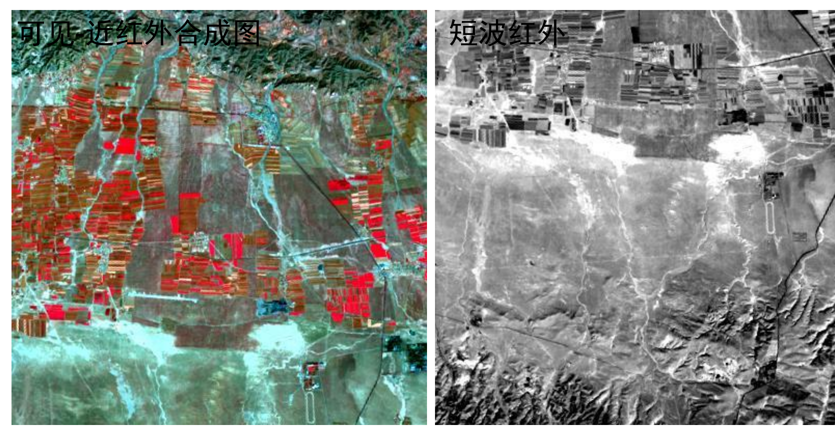
2018.9.23 SV1-02 MS（2m）/Pan（0.5m）



2018.9.21 Sentinel-2B MS（10m）



2018.9.23 SV1-04 MS（2m）/Pan（0.5m）

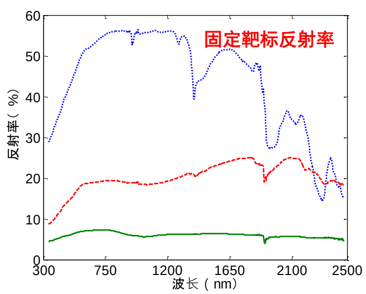


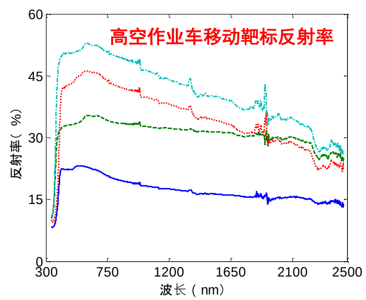
2018.10.4 Landsat 8

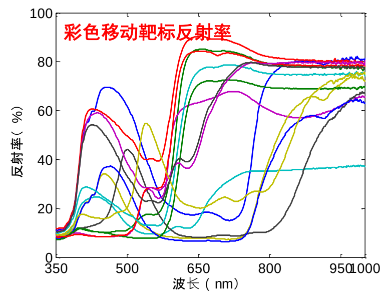
3. Flight Campaign

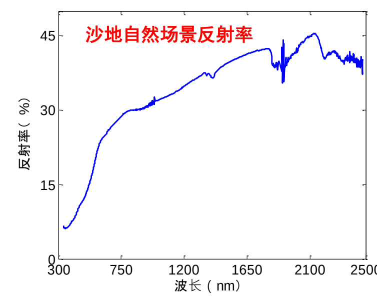
Surface auxiliary data acquisition – surface reflectance

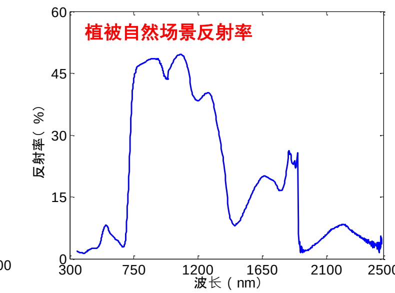
Within half an hour before and after the satellite overpass, the reflectance of permanent targets, portal targets, sand and cropland were measured with field spectrometer to validate our models and approaches.

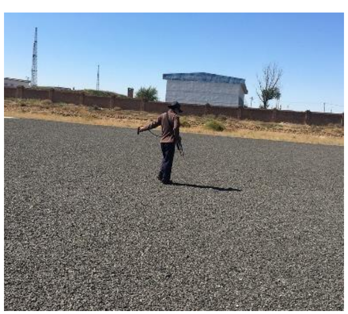




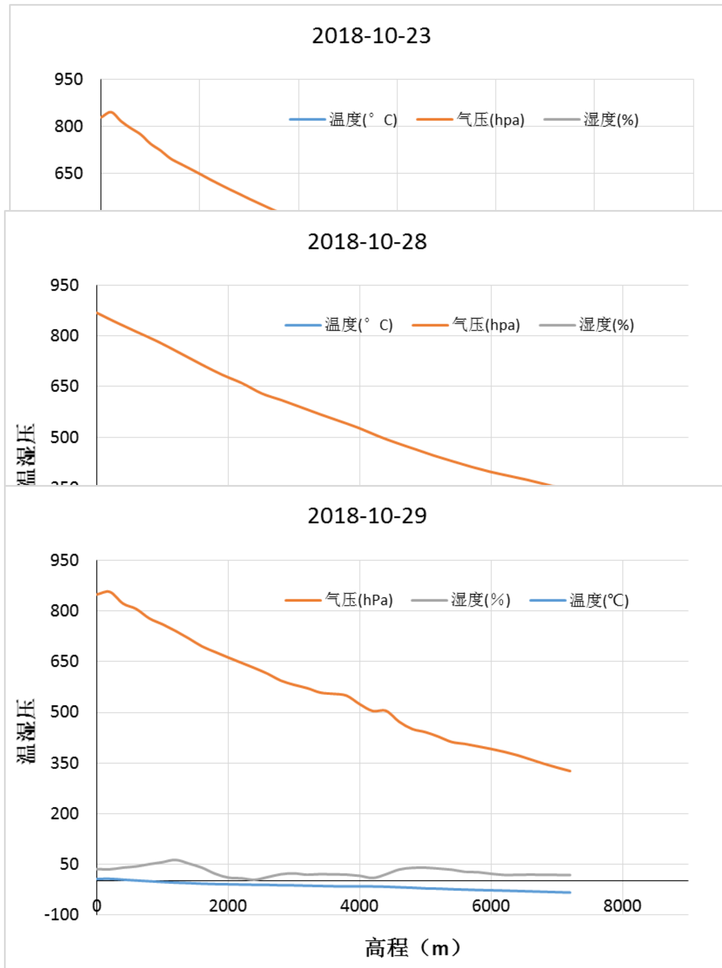




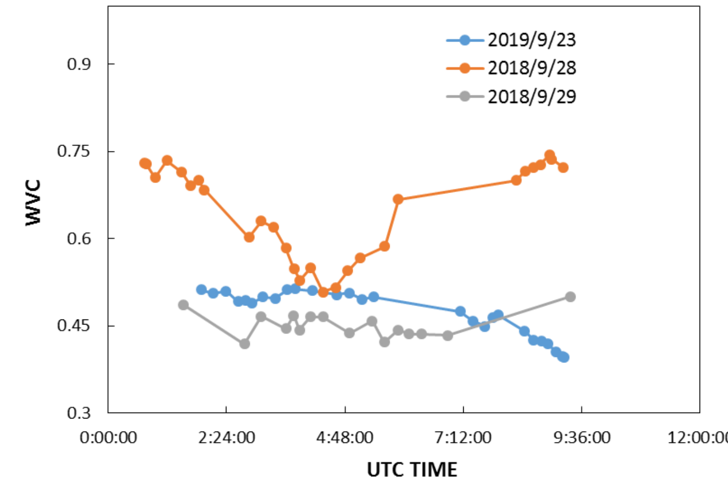


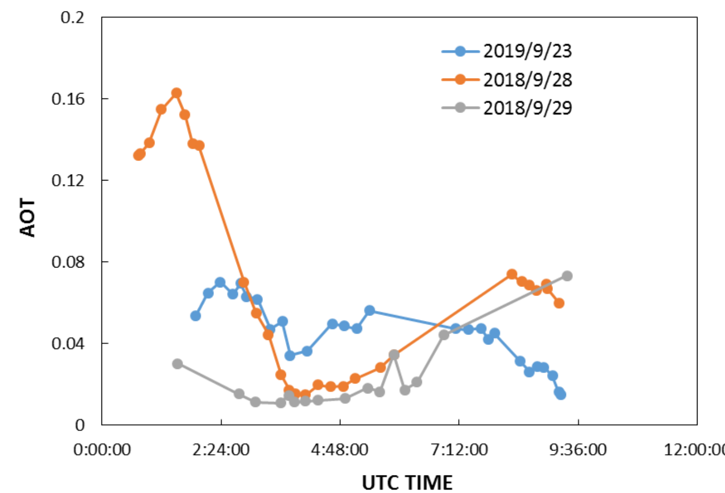


Surface auxiliary data acquisition – atmospheric parameters



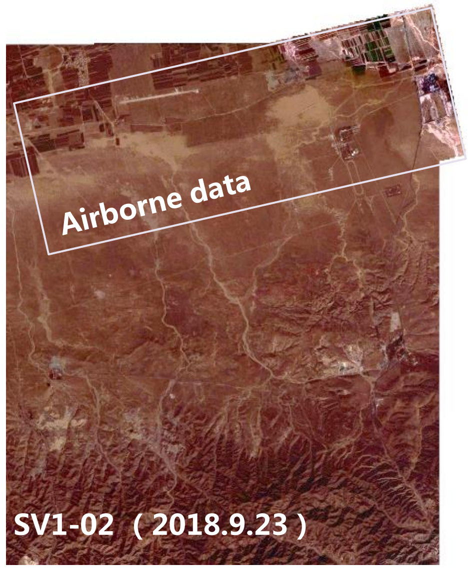
Atmospheric profiles



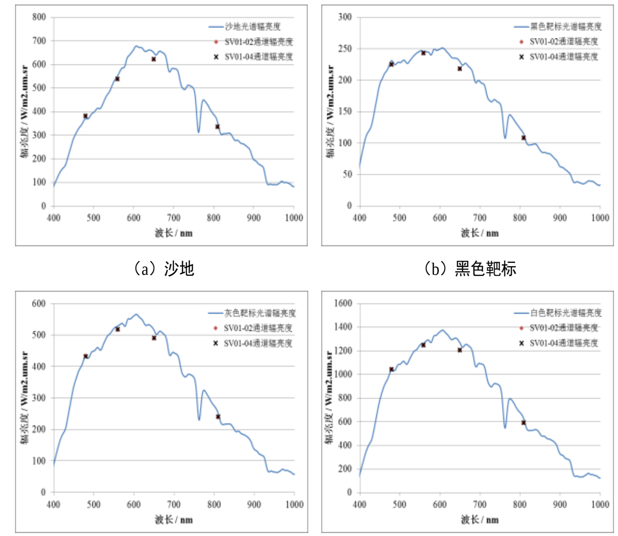


4. Preliminary results

Spatial matching



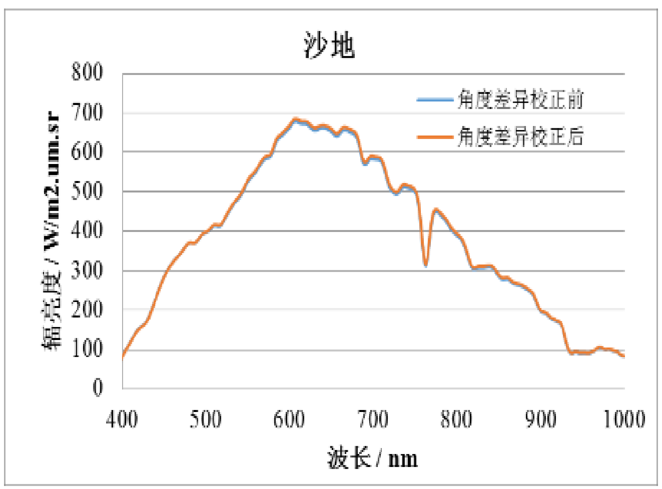
Spectral convolution



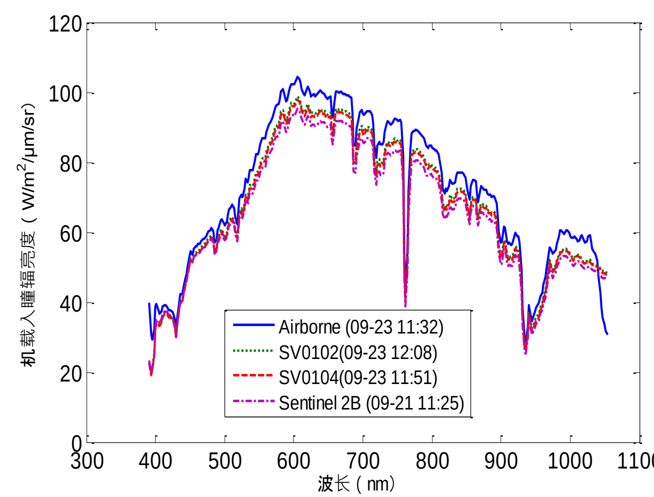
（a）沙地 （b）黑色靶标

（c）灰色靶标 （d）白色靶标

BRDF correction

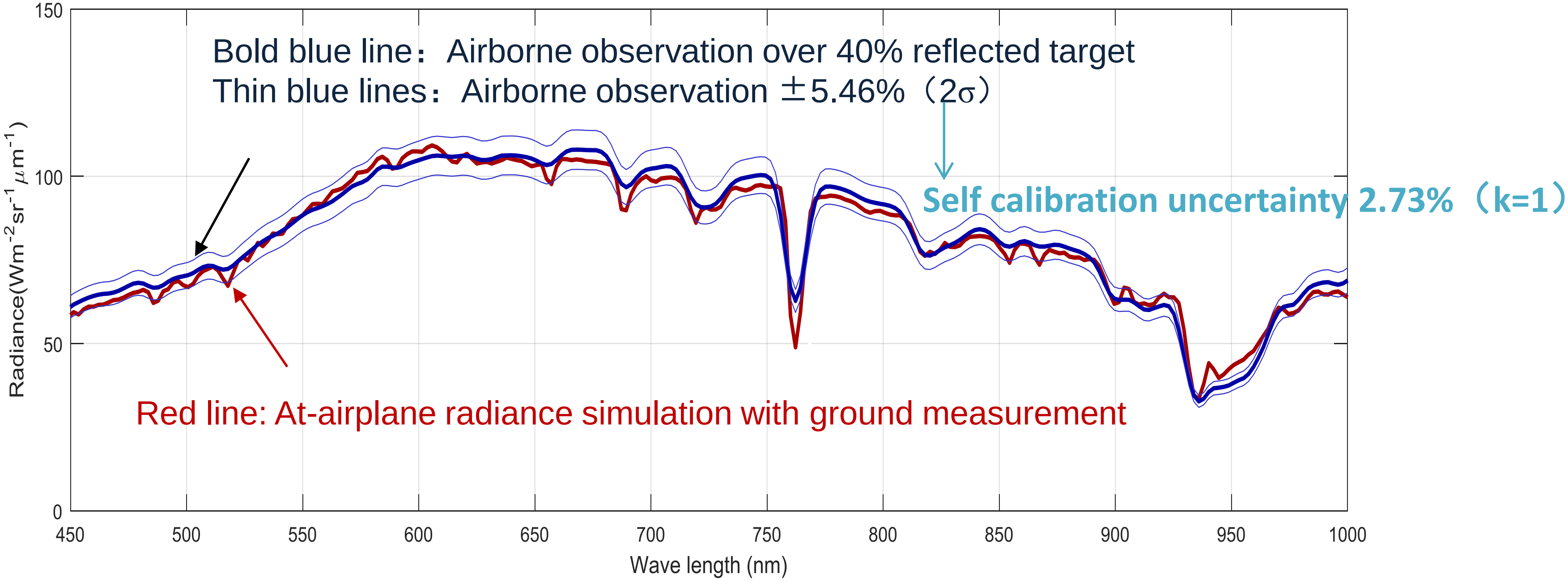


Temporal difference correction



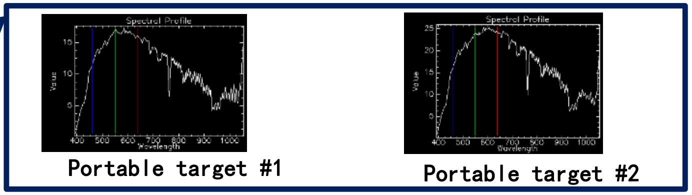
4. Preliminary results

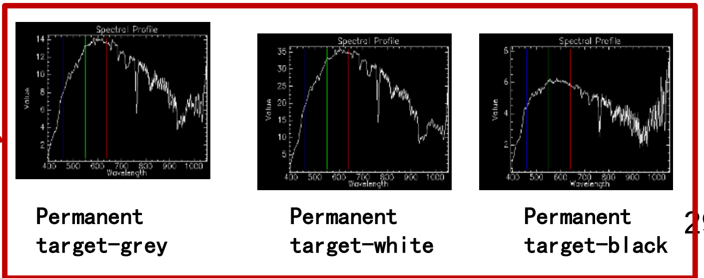
- Transfer calibration result between ground and airborne imager



Ground image

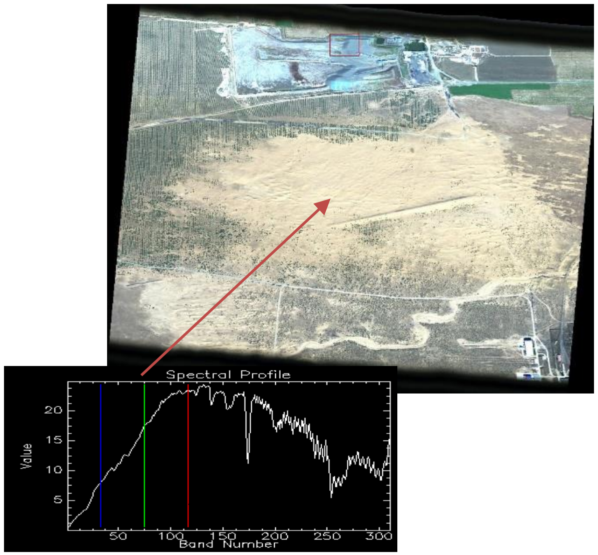
Airborne image





- Transfer calibration result between airborne and satellite imager

VNIR



Acquisition time：9.23 11:51

SV1-02
Acquisition time： 9.23 12:08

SV1-04
Acquisition time： 9.23 11:51

Sentinel 2B Acquisition time： 9.21 11:25

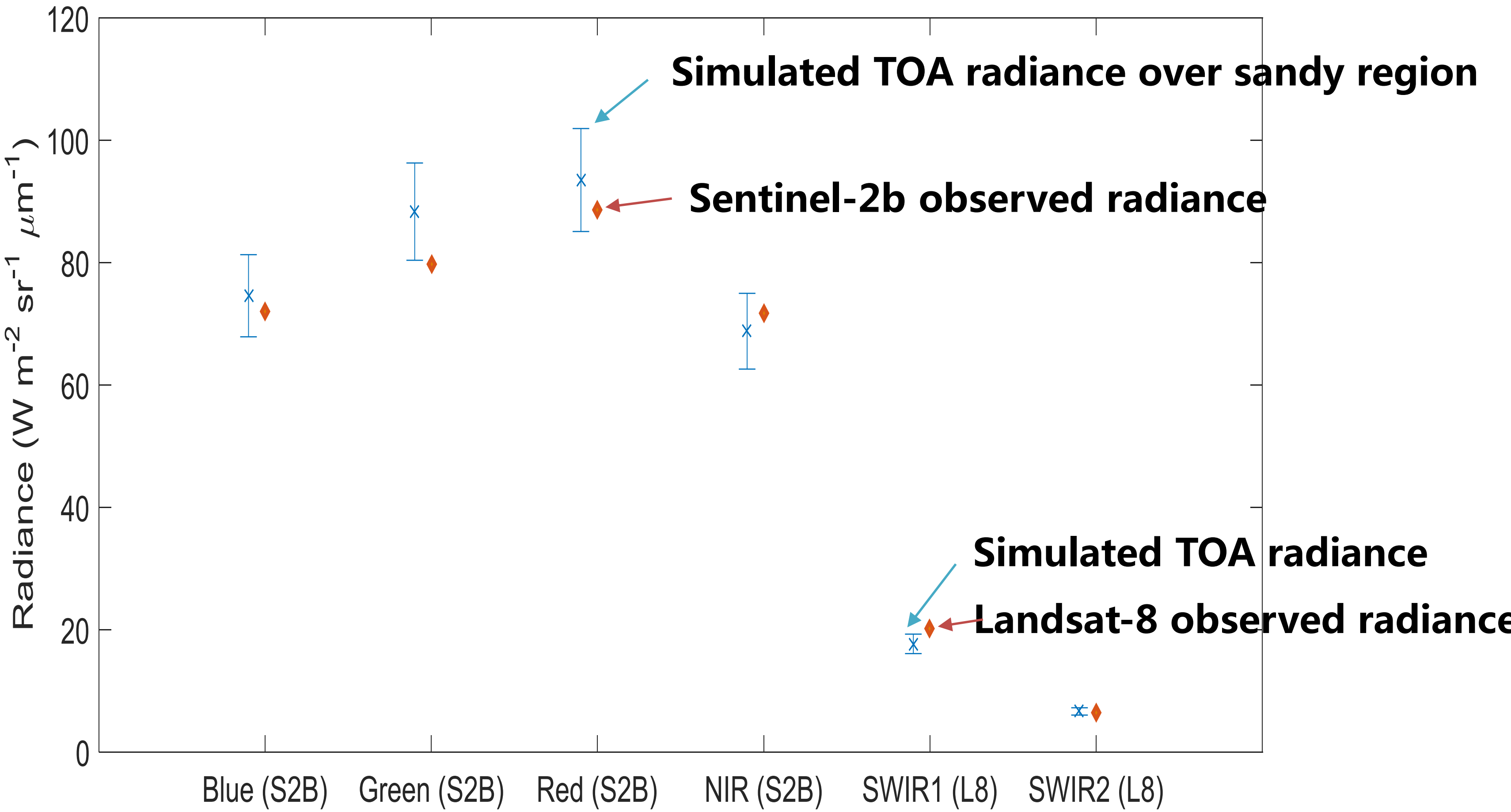
SWIR

Acquisition time： 9.29 13:14

LandSat 8 OLI
Acquisition time： 10.4 11:24

4. Preliminary results

- Transfer calibration result between airborne and satellite imager



5. Conclusion and future plans

- The consistent transfer calibration system contains:
  - multi-type ground test objects
  - airborne and ground-based hyperspectral imagers which both equip self-calibration device
  - multi-scale remote sensing data transform method.
- Flight campaign has been carried out to validate solar reflective bands in this transfer calibration system
- Validation of TIR band is in the planned, and uncertainty analysis need to be improved.
- SI-traceable spaceborne radiometric benchmark sensor is the future development objectives.

Thank you!

2. Composition

2.2 Standard ground-based and airborne hyperspectral imager

Uncertainty budget for ground imager

	Factors	VNIR	SWIR	LWIR
1	Sphere/BB uniformity	1.00%	1.00%	0.1K
2	Sphere/BB stability	0.50%	0.50%	0.1K
3	Radiance uncertainty	1.20%	1.40%	0.1K
4	Transfer uncertainty	0.27%	0.23%	0.2K
5	Imager stability	0.28%	0.35%	0.1K
6	Image response linearity	0.21%	0.52%	0.1K
7	Stray light	0.20%	0.20%	0.05K
	Total uncertainty	**1.71%**	**1.92%**	**0.30K**

Uncertainty budget for airborne imager

	Factors	VNIR	SWIR	LWIR
1	Sphere/BB uniformity	≤1.0%	≤1.0%	0.1K
2	Sphere/BB stability	≤0.5%	≤0.5%	≤0.1K
3	Radiance uncertainty	≤1.20%	≤1.40%	≤0.1K
4	Transfer uncertainty	0.44%	0.24%	0.3K
5	Imager stability	0.41%	0.24%	0.2K
6	Image response linearity	0.49%	0.20%	0.11K
7	Stray light	≤0.95%	≤1.0%	≤0.1K
	Total uncertainty	**≤1.83%**	**≤1.85%**	**≤0.43K**