Uncertainty Evaluations of the CRCS In-orbit Field Radiometric Calibration Methods for Thermal Infrared Channels of FENGYUN Meteorological Satellites

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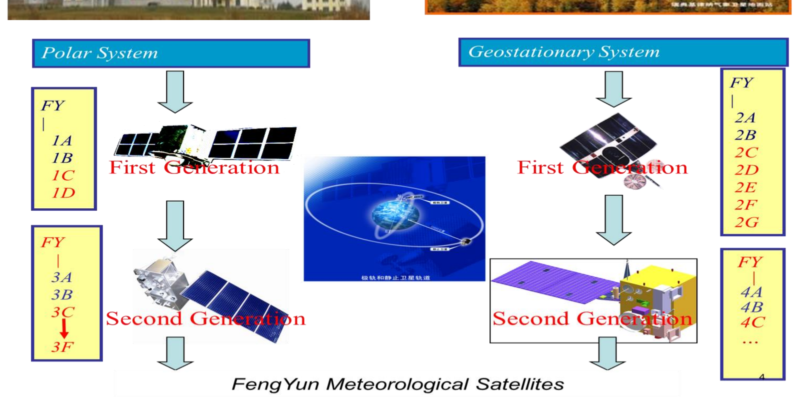
Abstract

- Meteorological satellites have become an irreplaceable weather and ocean-observing tool in China. These satellites are used to monitor natural disasters and improve the efficiency of many sectors of Chinese national economy. It is impossible to ignore the space-derived data in the fields of meteorology, hydrology, and agriculture, as well as disaster monitoring in China, a large agricultural country. For this reason, China is making a sustained effort to build and enhance its meteorological observing system and application system. The first Chinese polar-orbiting weather satellite was launched in 1988. Since then China has launched 16 meteorological satellites, 8 of which are sun synchronous and 8 of which are geostationary satellites; China will continue its two types of meteorological satellite programs.
- In order to achieve the in-orbit absolute radiometric calibration of the operational meteorological satellites' thermal infrared channels, China radiometric calibration sites (CRCS) established a set of in-orbit field absolute radiometric calibration methods (FCM) for thermal infrared channels (TIR) and the uncertainty of this method was evaluated and analyzed based on TERRA/AQUA MODIS observations. Comparisons between the MODIS at pupil brightness temperatures (BTs) and the simulated BTs at the top of atmosphere using radiative transfer model (RTM) based on field measurements showed that the accuracy of the current in-orbit field absolute radiometric calibration methods was better than 1.00K (@300K, K=1) in thermal infrared channels. Therefore, the current CRCS field calibration method for TIR channels applied to Chinese metrological satellites was with favorable calibration accuracy: for 10.5-11.5μm channel was better than 0.75K (@300K, K=1) and for 11.5-12.5μm channel was better than 0.85K (@300K, K=1).

Introduction

➢National Satellite Meteorological Center (NSMC) was founded in 1971, The main responsibilities of NSMC are as follows:

- to make plan for China's meteorological satellite development; define user requirements for the meteorological satellite system;
- to operate the meteorological satellite system; to receive, process, archive and disseminate satellite data to end users;
- to provide information service based on meteorological satellite data for weather forecast, climate prediction, the earth environment monitoring, and space weather monitoring and globe warning;
- to promote nation-wide utilization of meteorological satellite data based on research on algorithms, development of products; provide user with technical guidance on meteorological satellite remote sensing;
- entrusted by China Meteorological Administration, to exercise supervision and management for the implementation of satellite engineering project contracts.



FengYun Meteorological Satellites

FENGYUN satellites

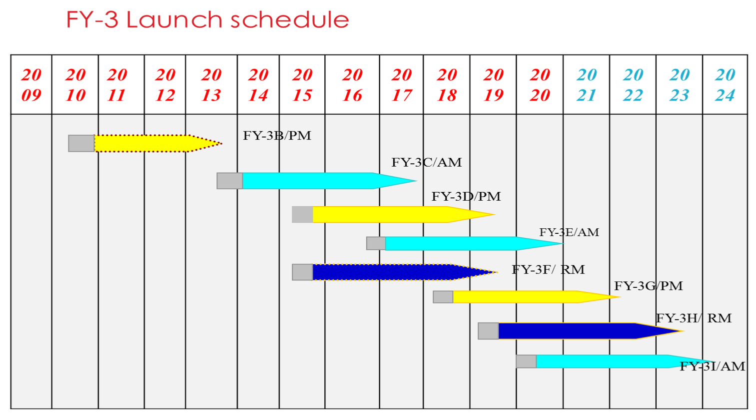
➢FENGYUN series satellites

- The Chinese meteorological satellites Fengyun, or FY in acronym, take place in series. The odd number series is the polar-orbiting satellite series, the even number series the geostationary. Each satellite takes the alphabetic order according to its seat in launching sequence. For instance, the 'FY-2G' indicates the seventh satellite that has been launched in the FY-2 geostationary series.
- Usually, the first two satellites are of experimental purpose in a series before it becomes fully operational; for smooth transition, launching of a new series satellite is arranged in time to allow for parallel operating till the new series replaces the old.
- Development and implementation of FENGYUN Meteorological Satellite Programs is the national cause upon which converges the effort from many institutes that undertake the production of satellite and carrier rocket, launching, telemetry & control, as well as the ground application. It is by the join effort of these institutions a complete meteorological satellite application system has been established and NSMC has become the operator of both polar-orbiting and geostationary meteorological satellites.
- The first FY satellite was launched in 1988. Since then China has launched 16 meteorological satellites, 8 of which are sun synchronous and 8 of which are geostationary satellites; The FENGYUN satellites are becoming more and more important in protecting lives and property of people from natural disasters.

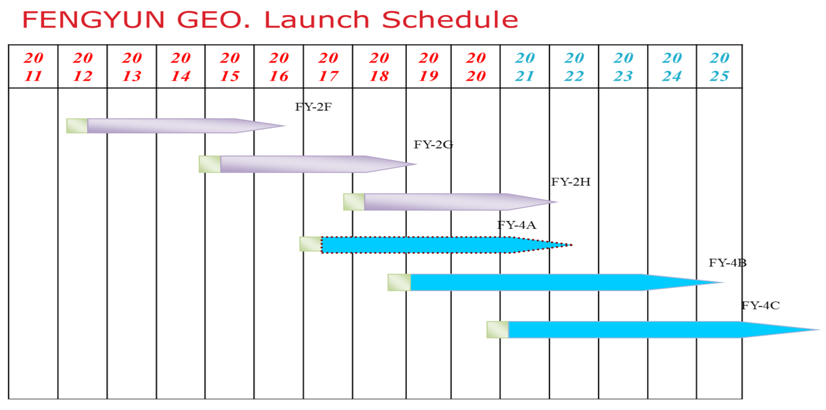
Sensors		SVISSR
Spectral channels (μm)	Visible	0.55-0.90
	Thermal infrared	10.30-11.30
		11.50-12.50
	Mid-infrared	3.50-4.00
	Water vapor	6.30-7.60
FOV per pixel (μrad)	Visible	35
	Thermal infrared	140
		140
	Mid-infrared	140
	Water vapor	140
Dynamic range	Visible（Albedo）	0-98%
	Thermal infrared（BT）	180K-330K
		180K-330K
	Mid-infrared（BT）	180K-340K
	Water vapor（BT）	190K-300K
Sensitivity	Visible（S/N）	S/N≥1.5(ρ=0.5%)S/N≥50 jcp=95%
	Thermal infrared (NEdT)	NE△T≤0.4-0.2K(@300K)
		NE△T≤0.4-0.2K(@300K)
	Mid-infrared (NEdT)	NE△T≤0.3-0.3K(@300K)
	Water vapor (NEdT)	NE△T≤0.6-0.5K(@260K)
Code type	Visible	6bits
	Infrared/Water vapor	10bits
Sampling rate	Visible	411.76KHz
	Infrared/Water vapor	102.94KHz
CFPA temperatures		Summer:100.3K Other: 93.5K

Specifications of FY-2 series satellites' SVISSR

FY-3 Launch schedule



FENGYUN GEO. Launch Schedule



National Program for FENGYUN Meteorological Satellites from 2011-2020

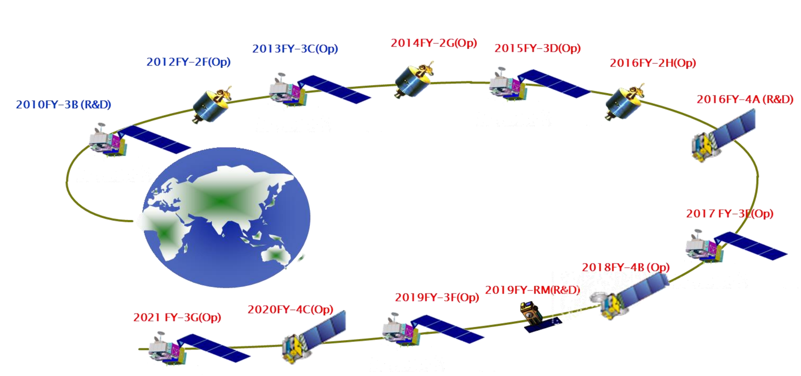


TABLE 2. *FY-3A* major remote sensing instruments. All spatial resolutions are for subsatellite points.

Instrument name	Major characteristics	Primary use
Sounding mission		
IRAS	Spectral range: 0.69 ~ 15.5 μm, channel numbers: 26, cross-track scanning: ±49.5° (2172 km), spatial resolution: 17.0 km	Atmospheric temperature profile, atmospheric humidity profile, total ozone content, cirrus, aerosol, etc.
MWTS	Frequency range: 50 ~ 57 GHz, channel numbers: 4, cross-track scanning: ±48.6° (2088 km), spatial resolution: 50 ~ 75 km	Atmospheric temperature profile, rainfall, cloud liquid water, surface parameters, etc.
MWHS	Frequency range: 150 ~ 183 GHz, channel numbers: 5, cross-track scanning: ±53.38° (2692 km), spatial resolution (SSP): 15 km	Atmospheric humidity profile, water vapor, rainfall, cloud liquid water, etc.
Ozone mission		
TOU	Spectral range: 309 ~ 361 nm, channel numbers: 6, cross-track scanning: ±56.0° (3020 km), spatial resolution: 50 km	Total ozone distribution
SBUS	Spectral range; 252 ~ 340 nm, channel numbers: 12, spatial resolution: 200 km	Ozone profile, total ozone amount
Imaging mission		
VIRR	Spectral range: 0.44 ~ 12.5 μm, channel numbers: 10, cross-track scanning: ±55.4° (2916 km), spatial resolution: 1.1 km	Cloud, vegetation, snow and ice, SST, LST, water vapor, aerosol, ocean color, etc.
MERSI	Spectral range: 0.41 ~ 12.5 μm, channel numbers: 20, cross-track scanning: ±55.4° (2916 km), spatial resolution: 0.25 ~ 1 km	True color imagery, cloud, vegetation, snow and ice, ocean color, aerosol, rapid response products (fires, flooding, etc.)
MWRI	Frequency range: 10.65 ~ 89 GHz, channel numbers: 10 (5 frequencies with H, V polarization), conical scanning: 110.8° (1430 km), spatial resolution: 15–80 km	Rainfall, soil moisture, cloud liquid water, sea surface parameters

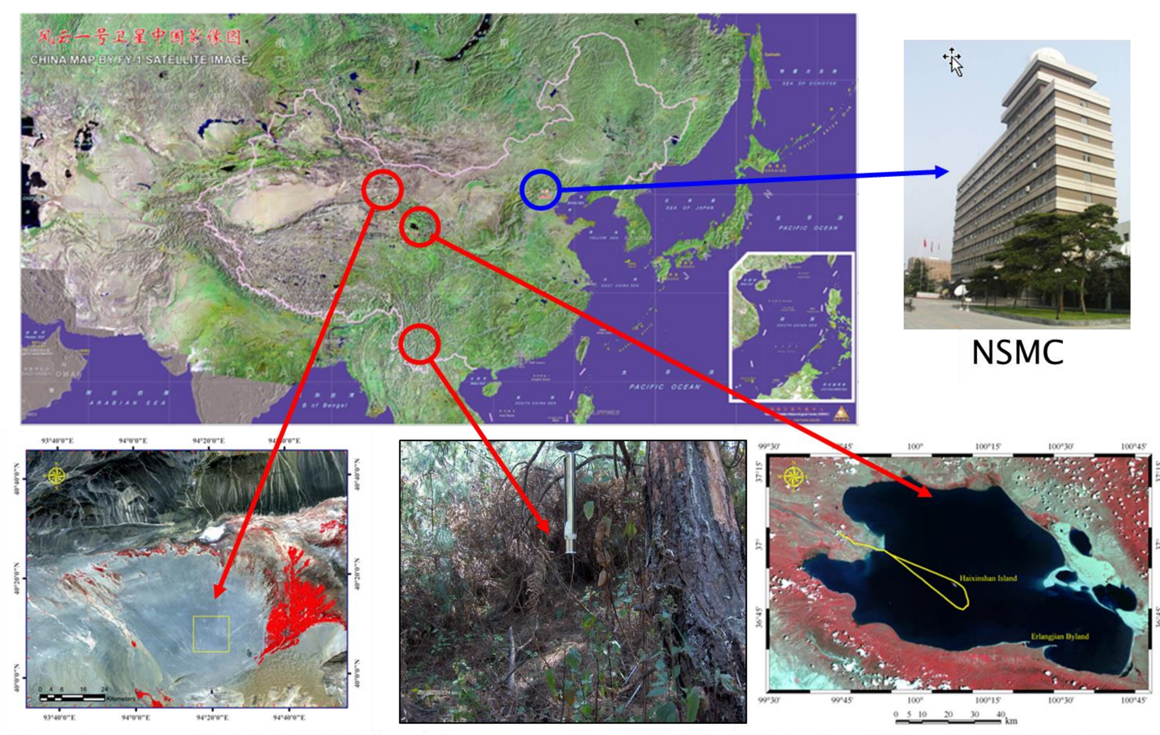
Specifications of FY-3 series satellites' IRAS, VIRR and MERSI

Channel	Band (μm)	Spatial Resolution (Km)	Detection Sensitivity		Main Application
Visible & Near-Infrared	0.45~0.49	1	S/N≥	70(ρ=100%)	Aerosol
	0.55~0.75	0.5~1		200(ρ=100%),5(ρ=1%)@0.5Km	Fog,Clound
	0.75~0.90	1			Vegetation
Short-wave Infrared	1.36~1.39	2	S/N≥	200 (ρ=100%) 5 (ρ=1%)	Cirrus
	1.58~1.64	2			Cloud,Snow
	2.1~2.35	2~4			Cirrus,Aerosol
Mid-wave Infrared	3.5~4.0(high)	2	NEΔT≤0.7K(300K)		Fire
	3.5~4.0(low)	4	NEΔT≤0.2K(300K)		Land surface
Water Vapor	5.8~6.7	4	NEΔT≤0.3K(260K)		WV
	6.9~7.3	4	NEΔT≤0.3K(260K)		WV
Long-wave Infrared	8.0~9.0	4	NEΔT=0.2K(300K)		WV,Clound
	10.3~11.3	4	NEΔT=0.2K(300K)		SST
	11.5~12.5	4	NEΔT=0.2K(300K)		SST
	13.2~13.8	4	NEΔT=0.5K(300K)		Clound,WV

Specifications of FY-4 series satellites' AGRI

CRCS calibration methods

China Radiometric Calibration Sites (CRCS)



Dunhuang Gobi (VNIR) Canopy Puer (MW) Lake Qinghai (TIR)

- Dunhuang Site: Gobi surface is combined with sandy soil and gravels, the mean diameter of the gravels is from 2cm to 5cm.The atmospheric conditions are dry and clean. It is a very good radiometric calibration site for satellites.
- Lake Qinghai Site: Lake Qinghai is the largest saline of China and located in the northeast of Tibet Plateau. Its total area is 4473 km^2 and the perimeter is 360km The elevation of the water surface is 3196 m and the cubage of the lake is 105 Gm3. It is a good place for IR bands' calibrating.
- Puer Canopy Site: Puer rain forest is mainly for Microwave sensors.

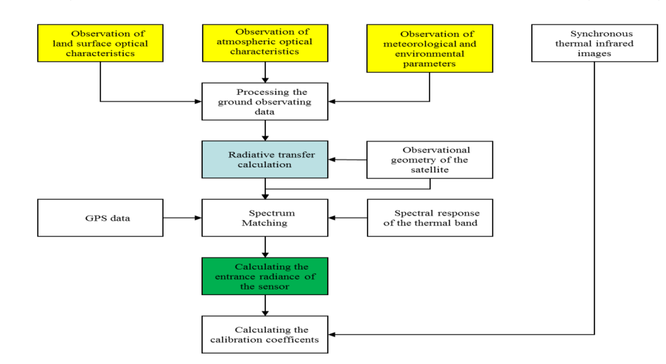
➢The CRCS in-orbit field absolute radiometric calibration methods (FCM) for thermal infrared channels (TIR)

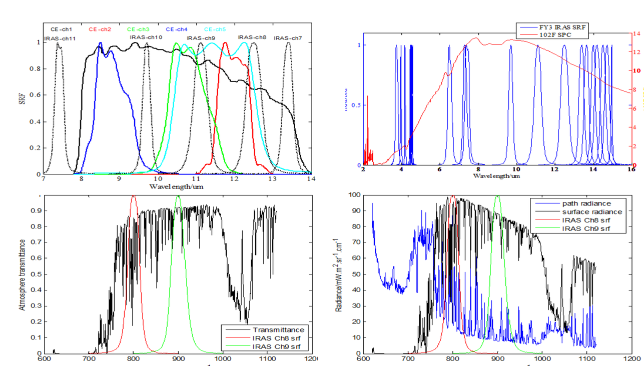
The infrared radiance entering the sensor has three components: the thermal radiance radiated by the water surface and attenuated by the atmosphere, the upward thermal radiance of the atmosphere, and the radiance (including the downward thermal radiance of the atmosphere and the long wavelength radiance of the sun) reflected from the water surface and attenuated by the atmosphere.

The spectral radiance at the sensor's aperture can be expressed as

$$L_s(\lambda) = \tau_a L_q(\lambda) + L_u + \rho_q(\lambda)\tau_a(\lambda)L_d(\lambda)$$

where $\tau_a(\lambda)$ is the spectral transmittance of the atmosphere, $L_q(\lambda)$ is the thermal radiance radiated from the water surface at the sensor's orientation, $L_u(\lambda)$ is the upward radiance of the atmosphere at the sensor's orientation, $L_d(\lambda)$ is the downward radiance of the atmosphere, $\rho_q(\lambda)$ is the water surface's reflectance, and λ is the wavelength.





Uncertainty evaluations

- Uncertainty of the CRCS in-orbit field absolute radiometric calibration methods for thermal infrared channels was evaluated and analyzed based on TERRA/AQUA MODIS observations.
- Comparisons between the MODIS at pupil brightness temperatures (BTs) and the simulated BTs at the top of atmosphere using radiative transfer model (RTM) based on field measurements were carried out. Final uncertainty evaluations were based on following equation:

$$\Delta = \sqrt{\Delta^2_{modis} + \Delta^2_{field}}$$

- where Δ_{modis} is the calibration uncertainty of MODIS channels (≈ 0.1K, Zhengming Wan, et al (2002), XiaoXiong Xiong, et al (2009), David C. Tobin, et al (2006));
- Δ_{field} is the differences of MODIS observations and the field measurements results (top of atmosphere BTs between TERRA/AQUA MODIS and the Radiative Transfer Model simulated results).

Results

Synchronous observation information of TERRA/AQUA MODIS at Lake Qinghai and Dunhuang in 2010, 2011 and 2012

Date	Satellites	Site	Overpass time (BJT)	Sat zenith angle
2010.8.4	TERRA	Dunhuang	23:25	24.75°
2010.8.14	TERRA	Dunhuang	13:00	27.60°
2010.8.18	TERRA	Dunhuang	12:35	4.47°
2010.8.20	TERRA	Dunhuang	23:30	24.76°
2011.8.21	TERRA	Dunhuang	12:37	4.20°
2011.8.21	TERRA	Dunhuang	23:42	3.03°
2011.8.24	AQUA	Dunhuang	03:43	4.28°
2011.9.11	AQUA	Lake Qinghai	14:34	8.85°
2012.7.24	AQUA	Lake Qinghai	14:00	27.56°
2012.8.7	TERRA	Dunhuang	12:37	4.47°
2012.8.12	AQUA	Dunhuang	14:45	2.98°

Differences of TOA BTs between TERRA/AQUA MODIS and the RTM simulated results of all three years comparisons (unit K for BTs)

Year	MM.DD	Channel 31 (Sat-RTM)	Channel 32 (Sat-RTM)
2010	8.4	0.22325	-0.05455
	8.14	0.58616	-0.24791
	8.18	0.65557	-0.834
	8.20	-0.62101	-0.81241
2011	8.21	-	-0.985
	8.21(night)	-	-0.909
	8.24	-	-0.983
	9.11	-	-0.024
2012	7.24	0.78216	-0.16636
	8.7	-0.42682	-0.94475
	8.12	0.18694	-0.51506

➢Total uncertainty: 10.5-11.5μm channel was better than 0.75K (@300K, K=1)

➢Total uncertainty: 11.5-12.5μm channel was better than 0.85K (@300K, K=1).

Conclusions and discussions

➢Calibration uncertainty of the current in-orbit field absolute radiometric calibration methods was better than 1.00K (@300K) in thermal infrared channels.

➢The current CRCS field calibration method for TIR channels applied to Chinese metrological satellites was with favorable calibration and validation accuracy.

Uncertainty of each step of CRCS field calibration method for TIR channels was as belows:

SI(K)→field instruments blackbody→field instruments→ radiosound atmosphere profiles → RTM→satellites observations