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FIFTEENTH ASIA-OCEANIA METEOROLOGICAL SATELLITE USERS' CONFERENCE
THE JOINT 2025 FENGYUN SATELLITE USER CONFERENCE

Artificial Intelligence Radiometric Calibration and Digital Twin of Remote Sensing Sensors

Boyang Chen, Peng Rao, Na Xu, et al

National Satellite Meteorological Center

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目录

1.1 Radiometric Calibration and stable temperature conditions

The Working Group on Calibration and Validation (WGCV) of the Committee on Earth Observation Satellites (CEOS) define "Calibration":

The process of quantitatively defining the system response to known, controlled signal inputs.

——Belward, A. S. International co-operation in satellite sensor calibration; the role of the CEOS Working Group on Calibration and Validation. Adv. Space Res. 23, 1443–1448 (1999).

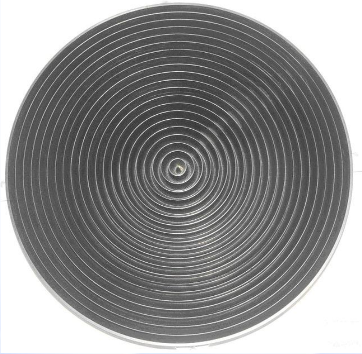
$$R=\sum_{k=0}^{K}a_k DN^k \dashrightarrow R=\mathrm{gains}\times DN+offset$$

$$a_k=fitting(R_i,DN_i);i=0,1,\cdots,N-1;k=0,1,\cdots,K-1$$

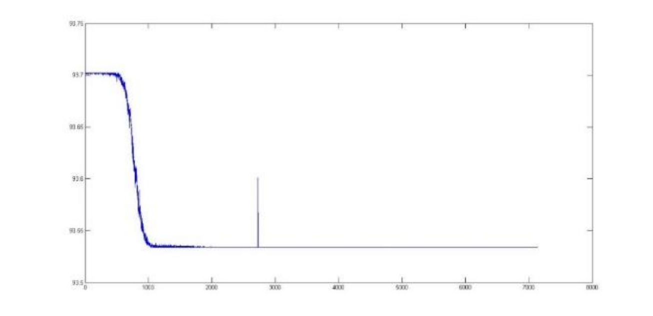
a_k The *kth* Calibarion Coefficient

(R_i,DN_i) The *ith* Pair of known, controlled radiometric source and its response

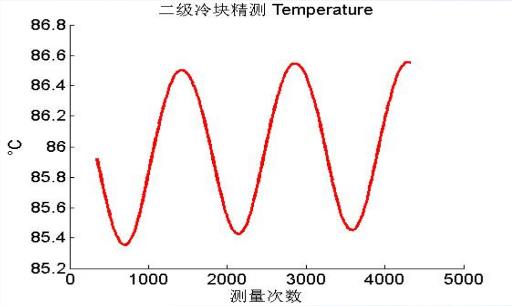
fitting (R_i,DN_i) To calculate a_k while $K \le N$



1.2 Unstable temperature of Radiant Cooler of AGRI on FY-4A



The temperatures of Radiant Cooler of FY-2（Stable）



Similar !
But Not
The Same

- Analyse the unstable temperatures ——supported by National Natural Science Foundation of China

项目批准号	42075134
申请代码	D0509
归口管理部门	
依托单位代码	10008108C0338-0656

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国家自然科学基金委员会

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亚类说明：

附注说明：

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填表日期：2020年09月28日

国家自然科学基金委员会制

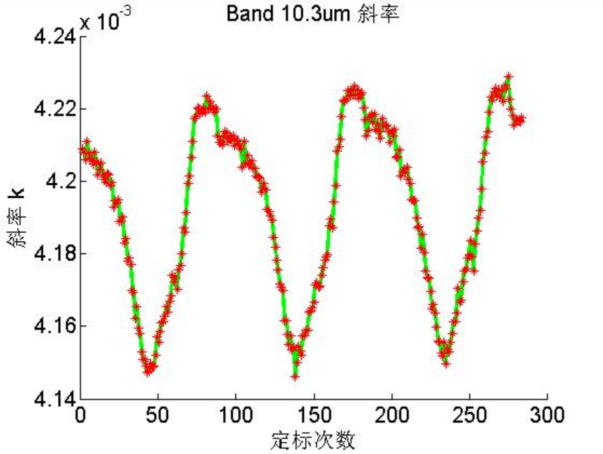
Version: 1.012.566

FY-4A:

FengYun-4 Geostationry Meteorological Satellite

AGRI:

Advanced Geostationary Radiation Imager



The slope of Channel 10.3 um of FY-4A/AGRI

1.3 Radiometric Calibration-Net for the relation between RC coefficients and temperatures

More details: (Boyang Chen, et al) IEEE TGRS, vol. 63, pp. 1-16, 2025
Radiometric Calibration using Artificial Intelligence: Constituting Uniform Observing System for Infrared Satellites
Download : https://ieeexplore.ieee.org/document/10855605

Calibration Equation:

$$I_{obc} = \sum_{k=0}^{K} a_k DN^k$$

Infrared sensor Equation:

$$I_{obc} = \frac{\sum_{j=1}^{N} z_j DN^j}{V_{noise}} \cdot \frac{\sqrt{A_d \Delta f}}{D^*} \cdot \frac{1}{\Omega A_d}$$

$$I_{\mathrm{obs}}^{\mathrm{PC}} = \sum_{j=0}^{N} \left[z_j \left(\frac{E_g\ t}{\Omega\ \eta\ \tau\ V_b}\ n_0 + \frac{E_g}{\Omega\ V_b}\ \phi_B \right) \mathrm{DR}^j \right]$$

$$I_{\mathrm{obs}}^{\mathrm{PV}} = \sum_{j=0}^{N} \frac{z_j\ h\ c\ n_0\ \mathrm{DR}^j}{\Omega\ A_d\ [n_0\ (\sigma_0 + \sigma_1) - \alpha\ \sigma_1\ w_0\ \phi_B]\ \lambda\ q\ \mathrm{IMP}_L}$$

PC: photoconductance-type sensors

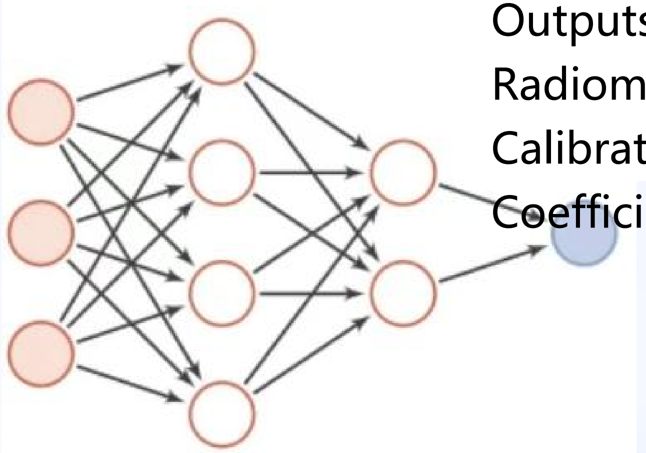
PV: photovoltaic-type sensors

$$\begin{aligned} a_j^{PC} &= \mathbb{F}_j^{PC}(h, c, \lambda, \Omega, A_d, n_0, E_g, t, \eta, \tau, V_b, SRF_s, l_s, T_s, k, z_j), \\ a_j^{PV} &= \mathbb{F}_j^{PV}(h, c, \lambda, q, \Omega, A_d, n_0, IMP_L, \sigma_0, \sigma_1, \alpha, w_0, SRF_s, \\ &\qquad l_s, T_s, k, z_j), \forall j \in [0, N]. \end{aligned} \tag{4}$$

For more concise annotation, in the following we both use a_j to represent a_j^{PC}, a_j^{PV}, and $\mathbb{F}_j$ to represent $\mathbb{F}_j^{PC}$, $\mathbb{F}_j^{PV}$. According to Equation 4, $\mathbb{F}_j$, or $\mathbb{F}$, is intrinsically complicated and varied conditions according to different sensors, e.g., for traditional SBRC methods, a_j is calculated by repetitively observing radiometric source over time, which is computationally expensive.

Inputs:
Temperatures from all the components in the optical paht of the sensor

T_s

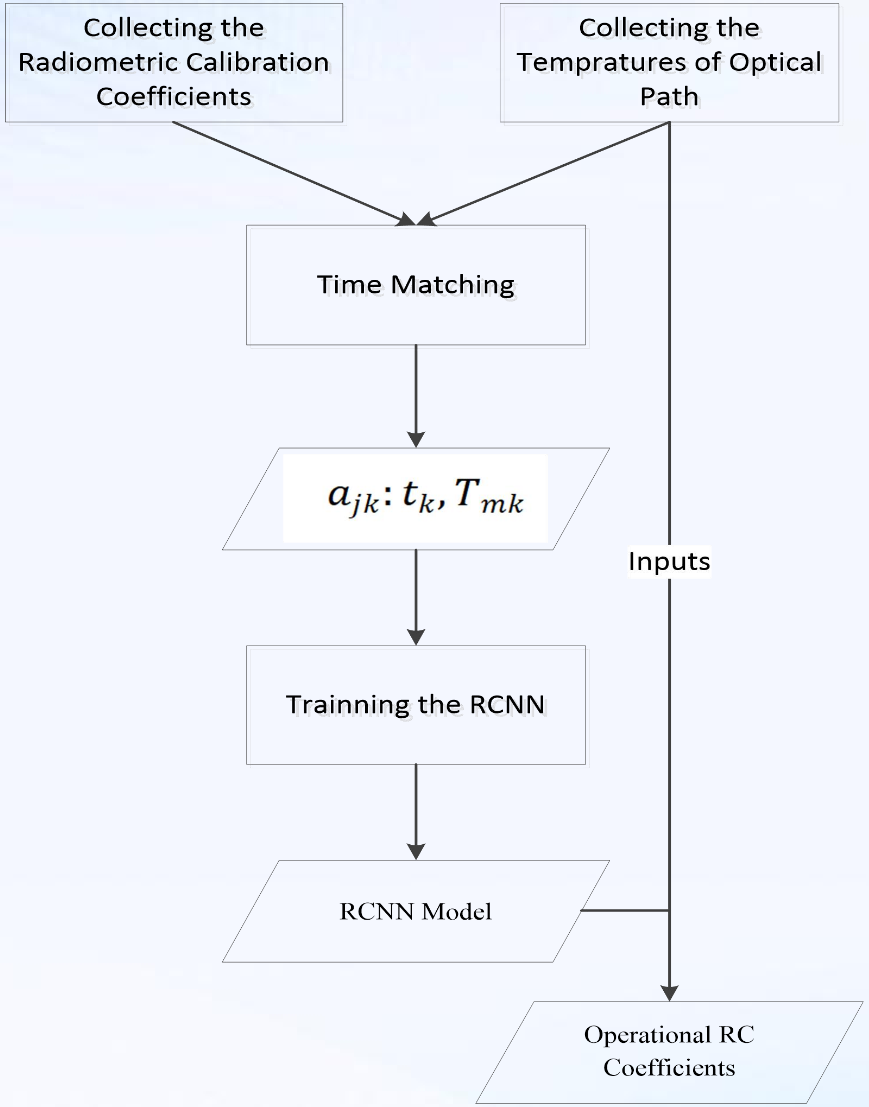


Outputs:
Radiometric Calibration Coefficients

a_i

Radiometric Calibration Neural Network (RCNN)

1.4 Workflow of AIRC



1. Collecting the RC coefficients and the temperatures of optical path
2. Time matching ang get training dataset:

   a_j RC coefficients

   t Time of calibrating

   T_m Temperatures of optical components

3. Train the RCNN
4. Operational RC using RCNN by inputting temperatures

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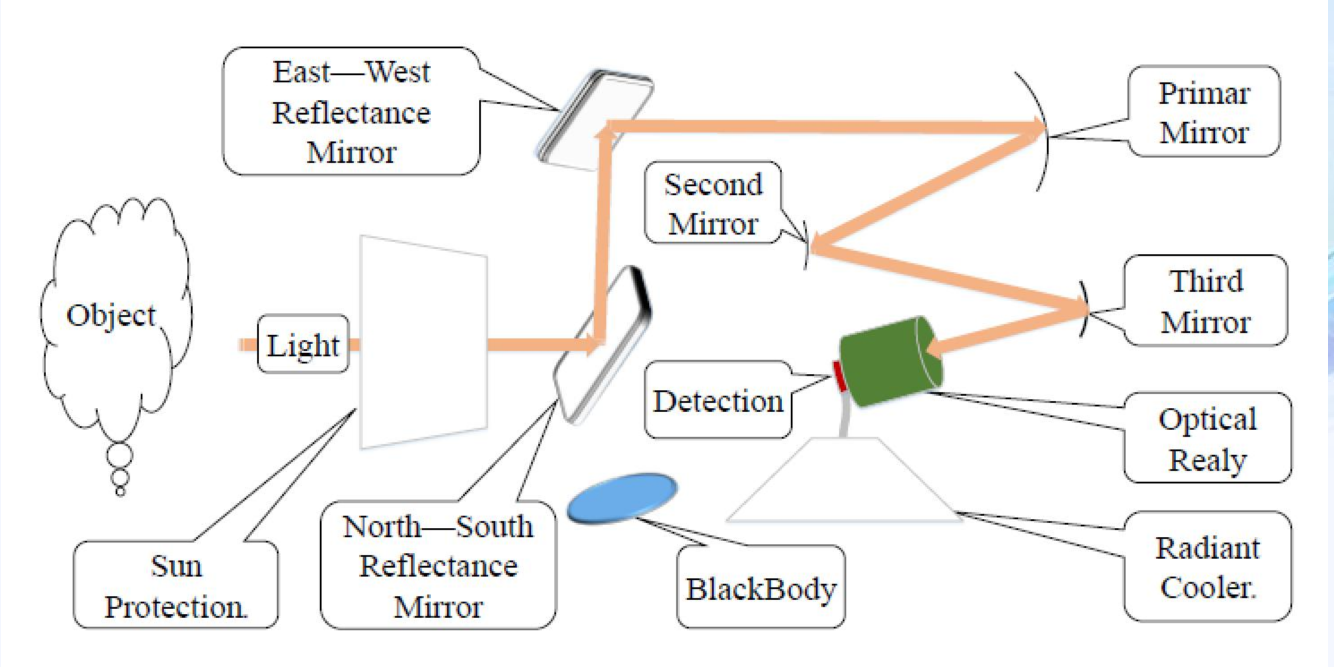
2.1 FY-4A AGRI ---- AIRC experiment in infrared band

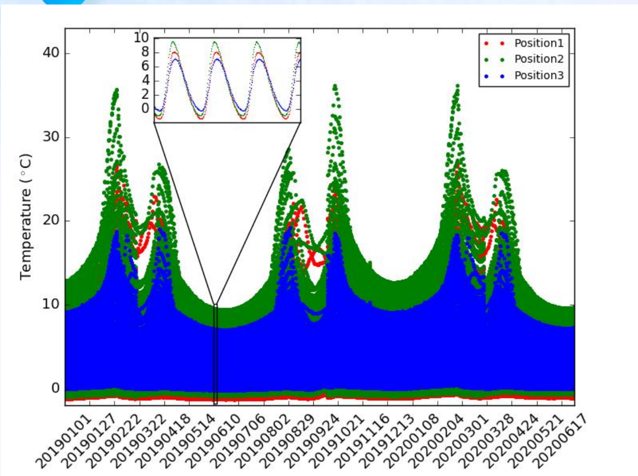
AGRI on FY-4A was launched on 11 Dec., 2016



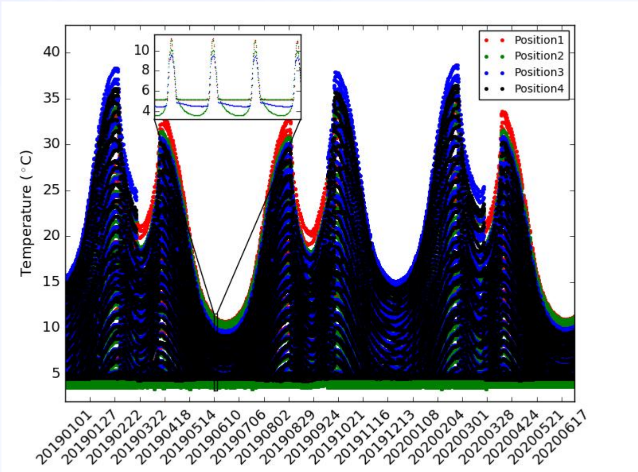
Optical Path of AGRI

- ➢ With an on-orbit blackbody
- • On-orbit Radiometric Calibration performance per 15 minutes
- ➢ The temperatures measurement to 8 components
- • Total 18 temperatures, some of components are more than 1 temperature measurement

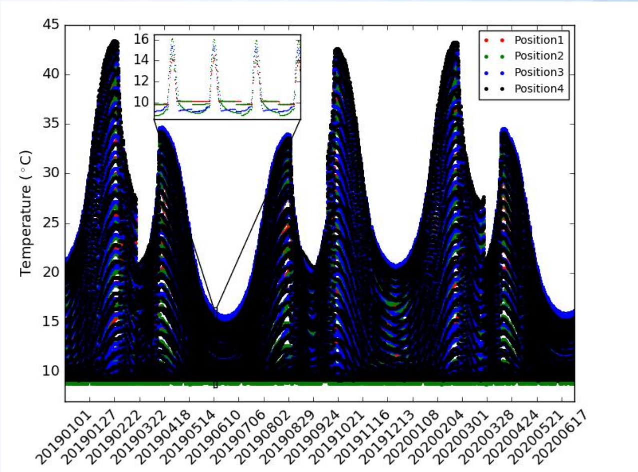
2.11 The temperatures of 8 components ---- Inputs of RCNN



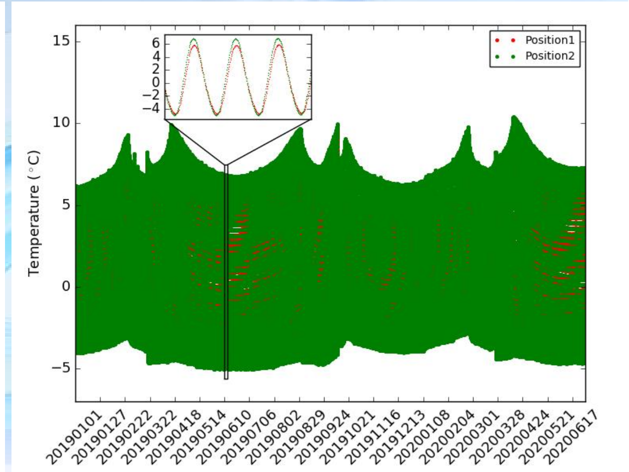
Sun Protection



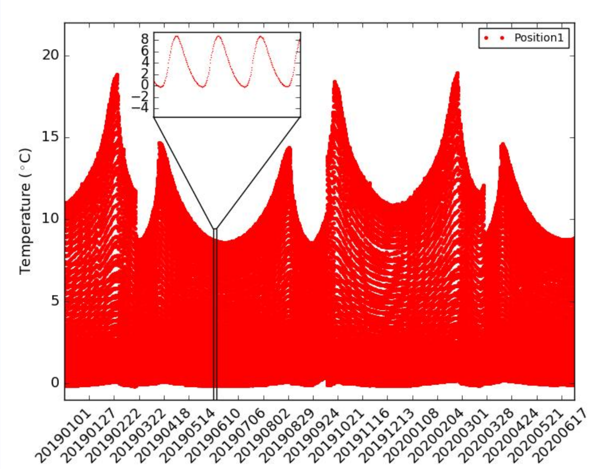
North-South Reflectance Mirror



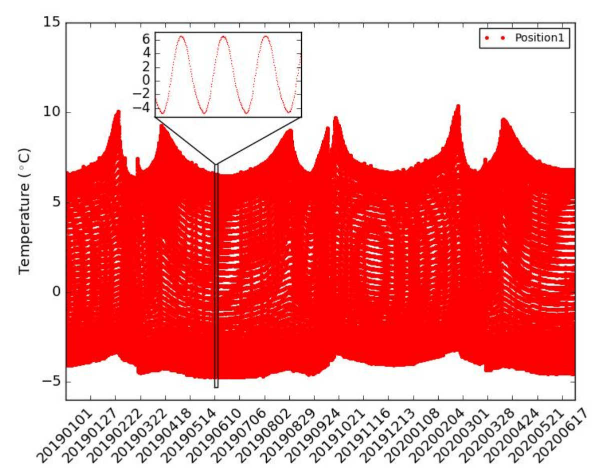
East-West Reflectance Mirror



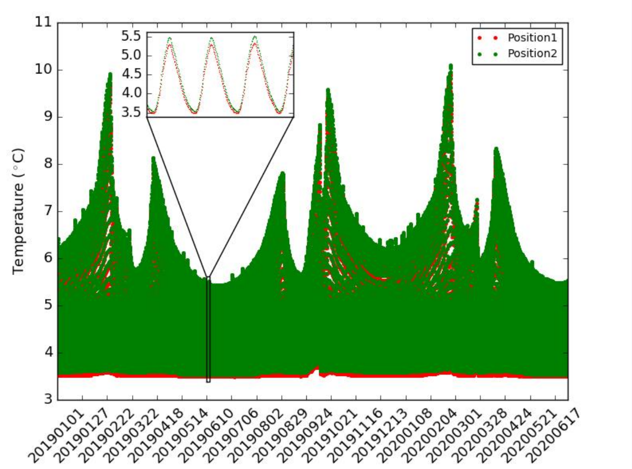
Primary Mirror



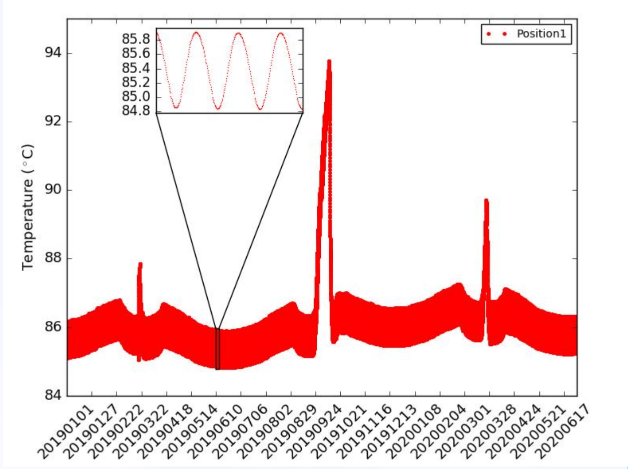
Second Mirror



Third Mirror

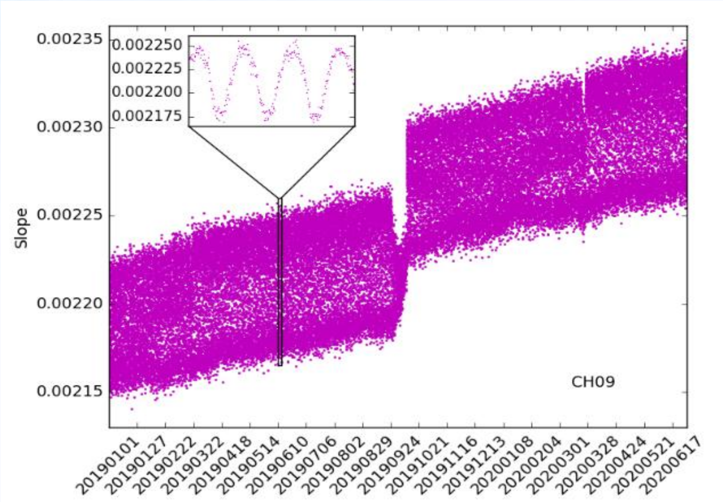


Optical Ralay

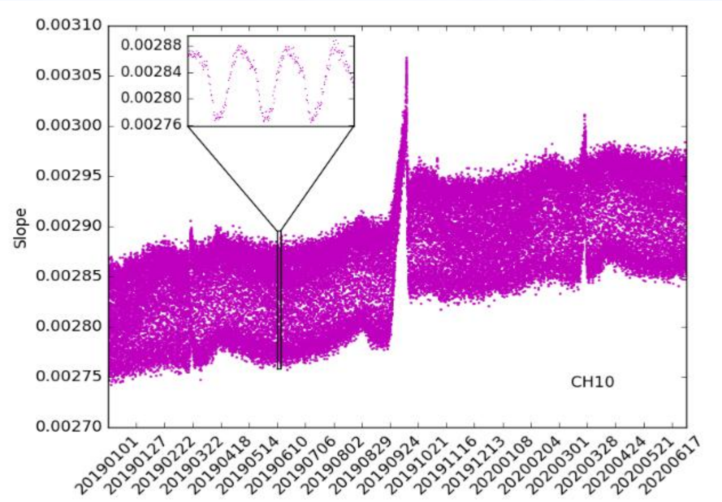


Radiant Cooler

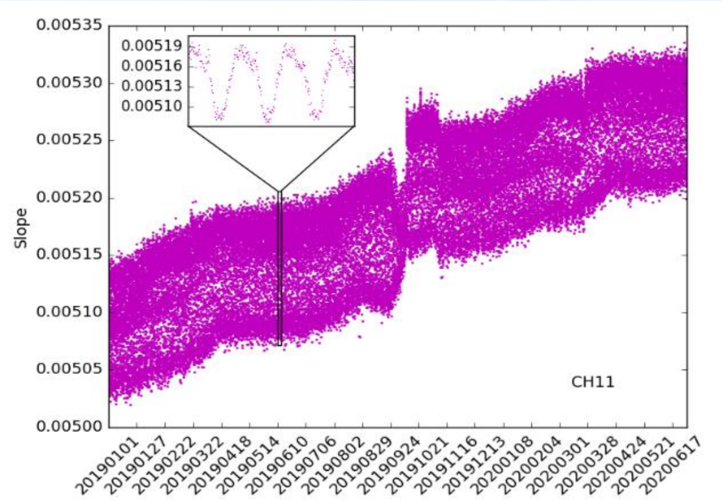
2.12 Radiometric Coefficients: Gains ---- Labels of RCNN



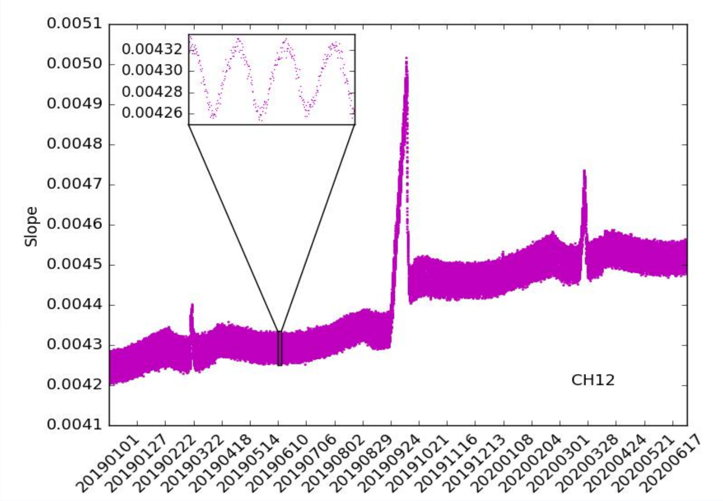
5.8-6.7μm



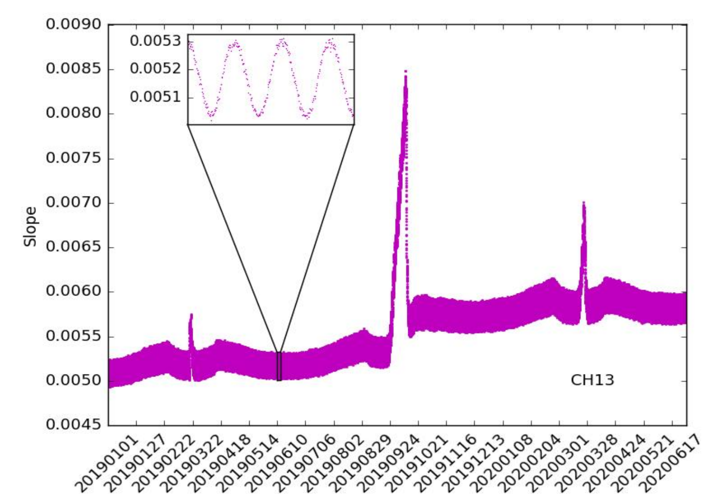
6.9-7.3μm



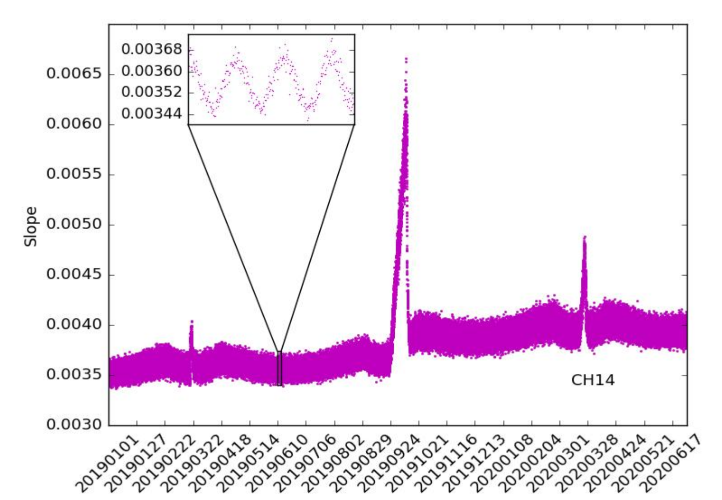
8.0-9.0μm



10.3-11.3μm

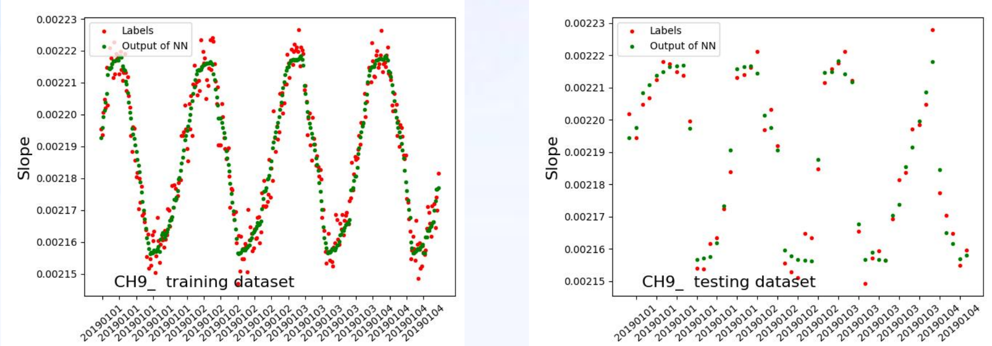


11.5-12.5μm

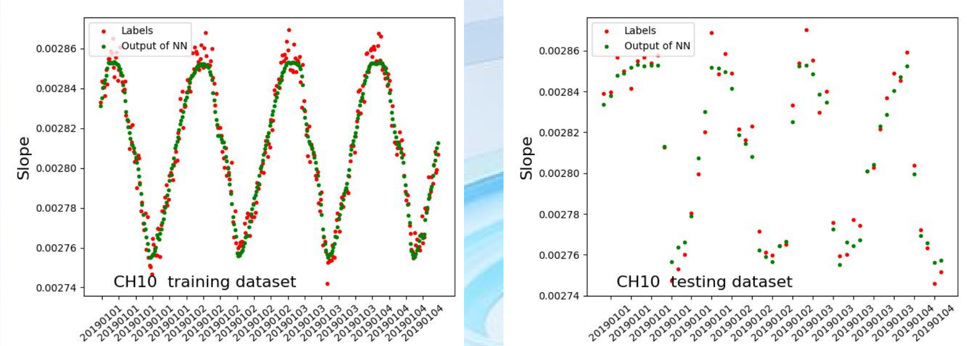


13.2-13.8μm

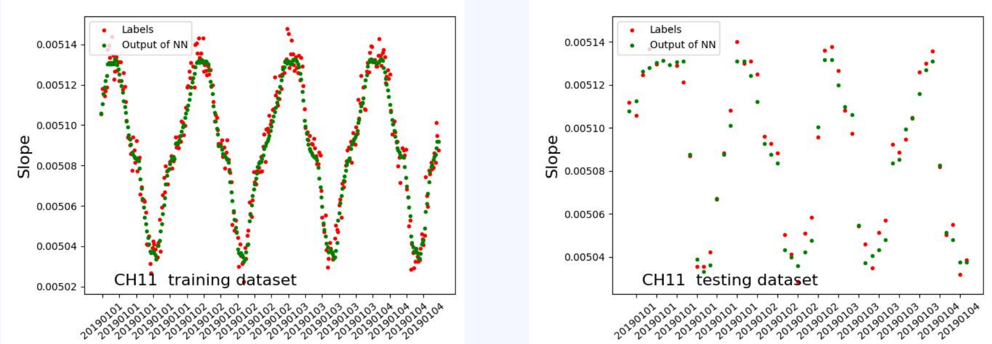
2.13 The results of AIRC----Comparisons of labels and outputs of RCNN



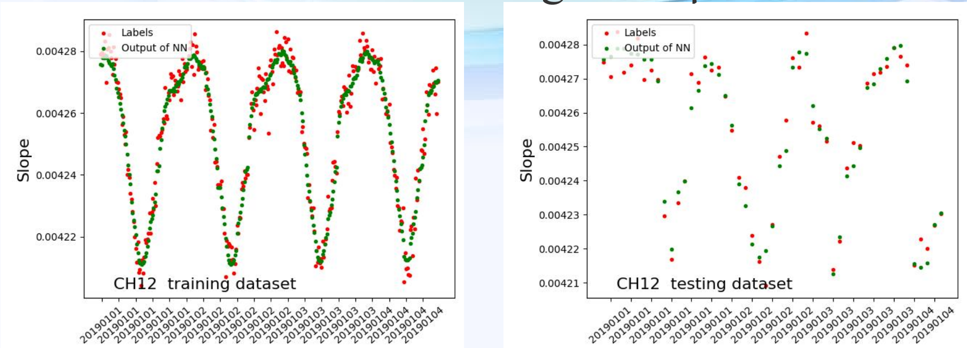
center wavelength: 6.25μm



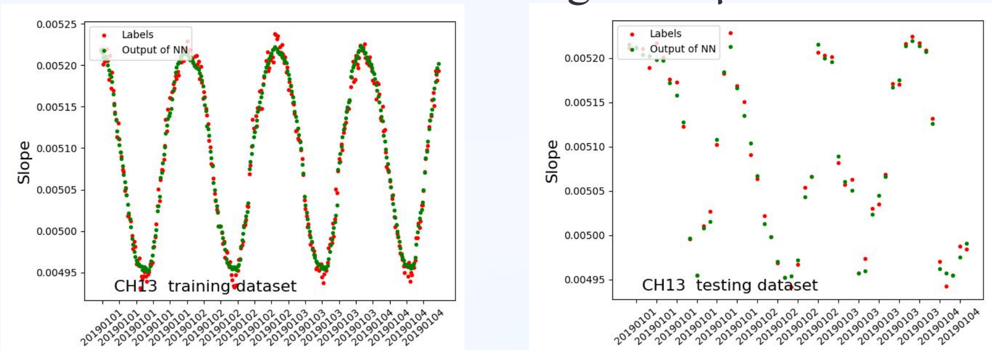
center wavelength: 7.1μm



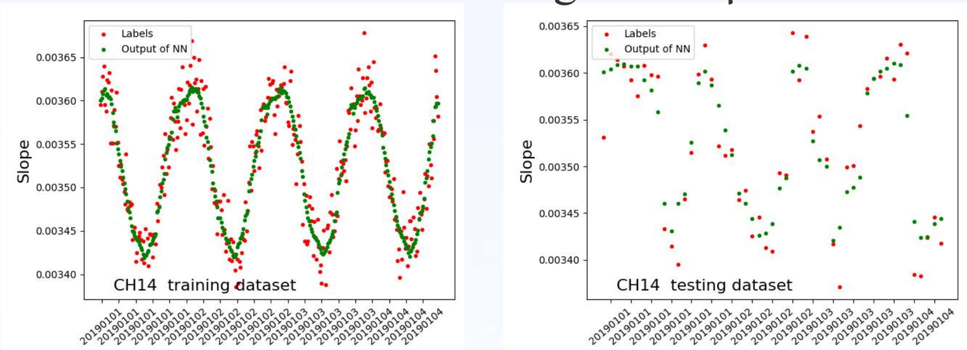
center wavelength: 8.5μm



center wavelength: 10.7μm

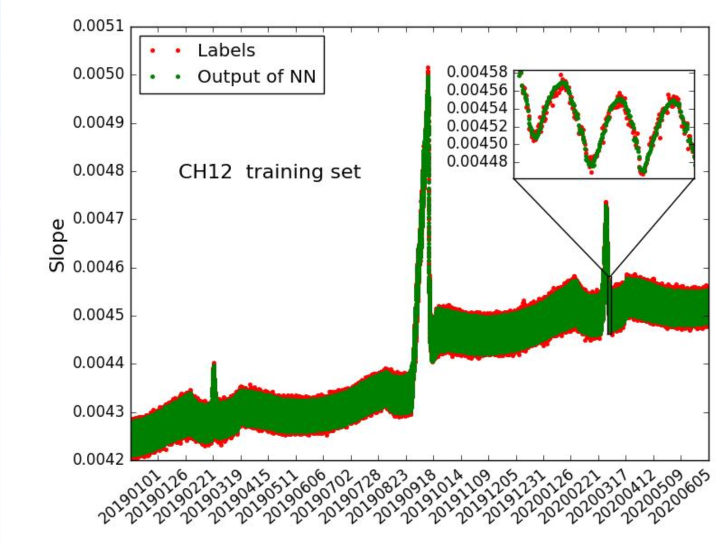


center wavelength: 12μm

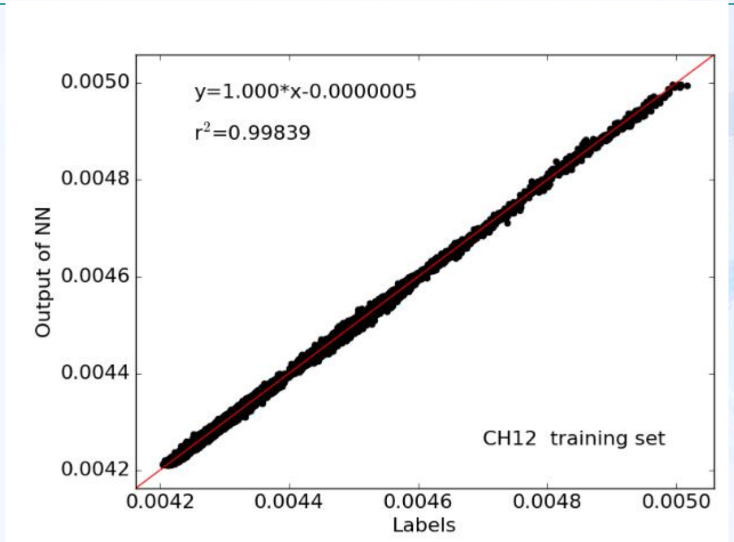


center wavelength: 13.5μm

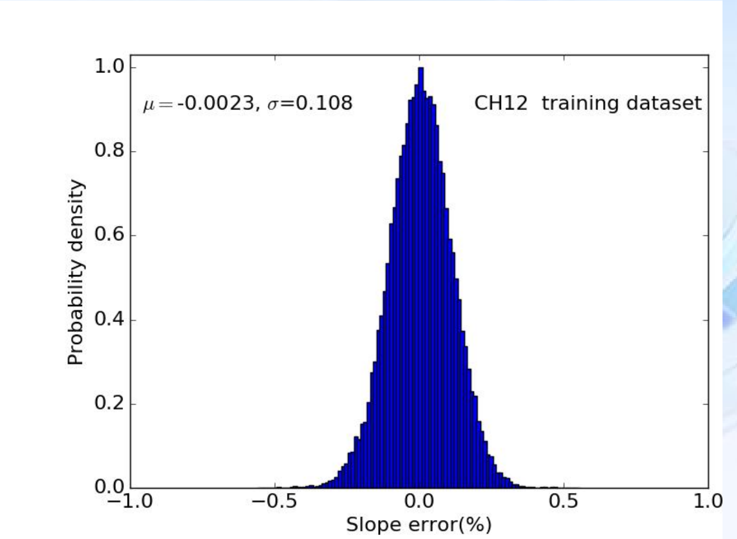
2.14 The results of AIRC----Comparisons between the outputs of RCNN and labels



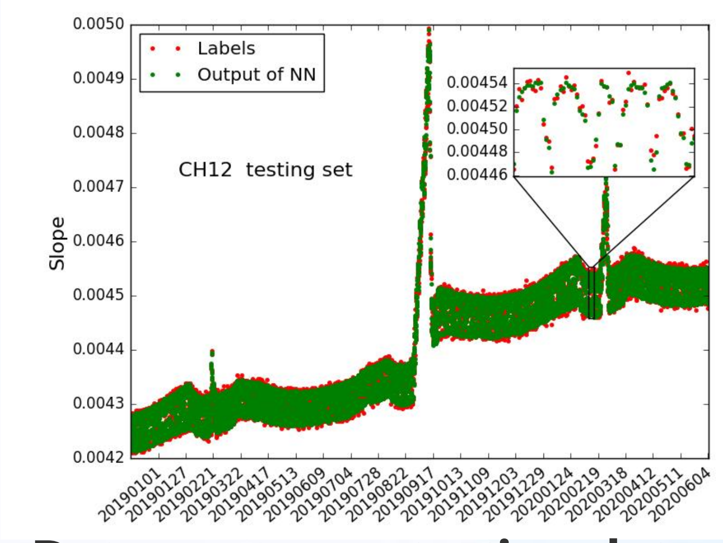
Data sequence-training dataset



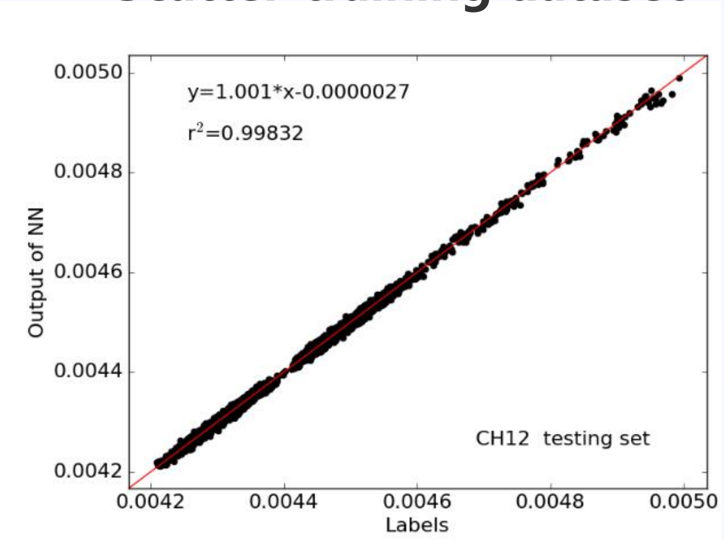
Scatter-training dataset



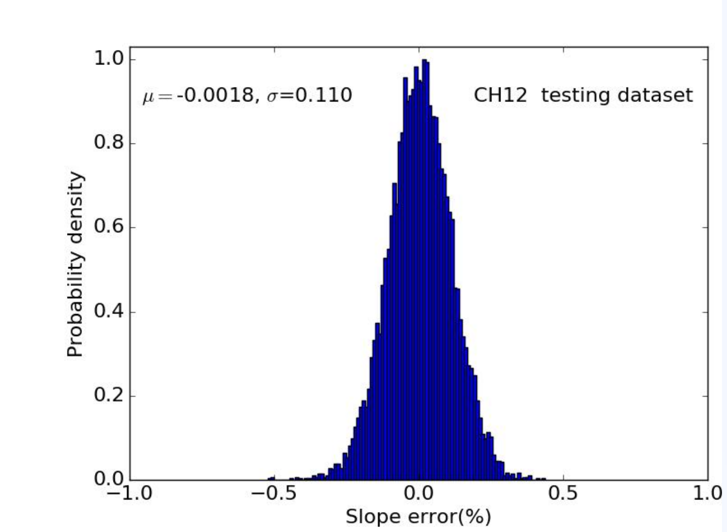
Statistics Analysis-training dataset



Data sequence-testing dataset



Scatt-testing dataset



Statistics Analysis-testing dataset

2.15 The evaluation of AIRC ---- for all the channels: gains error and BT erros.

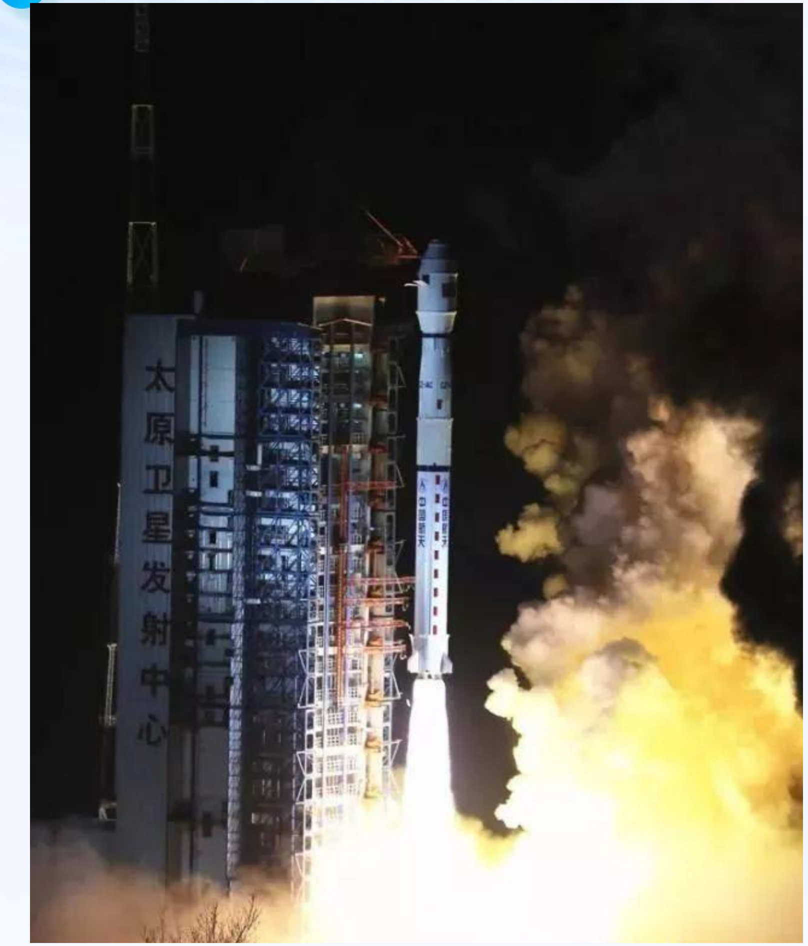
TABLE III

ANALYSIS OF PREDICTION ERROR WITH RESPECT TO THE PROPORTIONAL DIFFERENCE OF ERROR IN SLOPE (%) AND BRIGHTNESS TEMPERATURE ERROR (K)

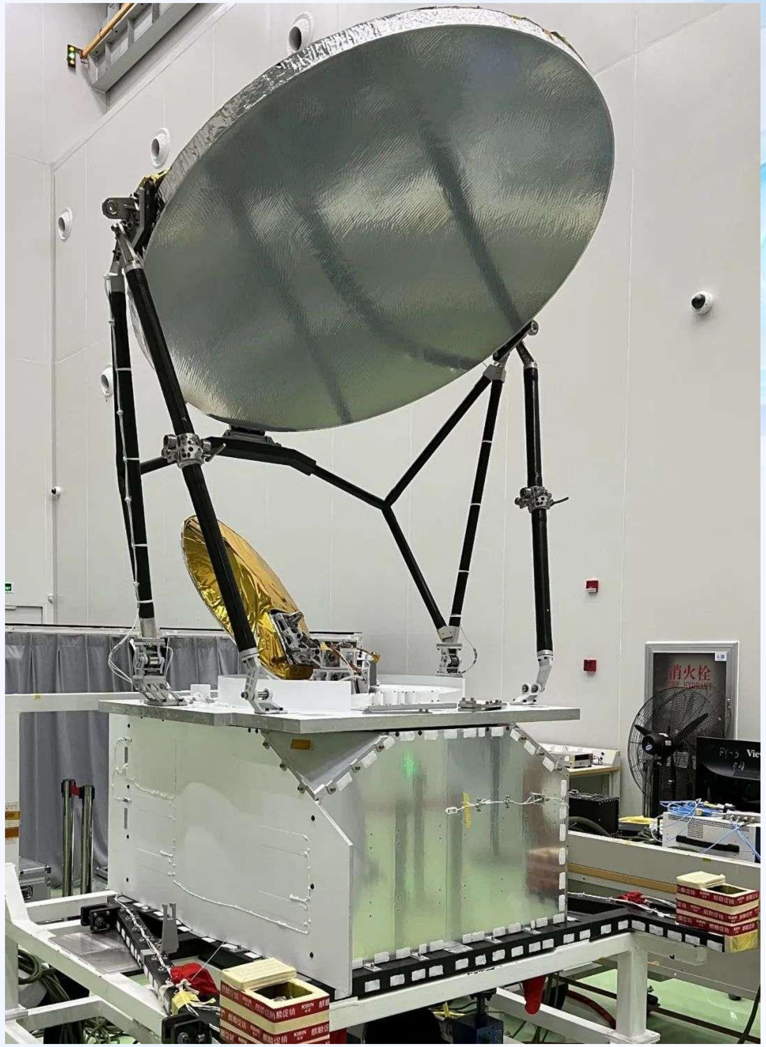
Channel	$\mu(\Delta)(\%)$		$\sigma(\Delta)(\%)$		Bright temperature error (K)	
	Training	Testing	Training	Testing	Mean Value	Standard Deviation
09	0.0060	0.0090	0.223	0.230	0.0027K@260K	0.068K@260K
10	0.0014	0.0026	0.222	0.228	0.00087K@260K	0.076K@260K
11	-0.0035	-0.0023	0.140	0.142	-0.0018K@290K	0.073K@290K
12	-0.0023	-0.0018	0.108	0.110	-0.0014K@290K	0.069K@290K
13	-0.0076	-0.0070	0.201	0.205	-0.0053K@290K	0.140K@290K
14	0.0236	0.0320	0.868	0.896	0.0200K@260K	0.890K@260K

The maximum mean error of all the channels is less than 0.02K@260K

2.2 FY-3D MWRI ---- AIRC experiment in microwave band



MWRI on FY-3D was launched on 15, Nov.11, 2017



MWRI

NO.	Input
1	antenna temperature
3	feed horn temperature
4	receiver temperature
5	receiver-control voltage
6	number of days since launch

NO.	Output
1	gains
2	offset

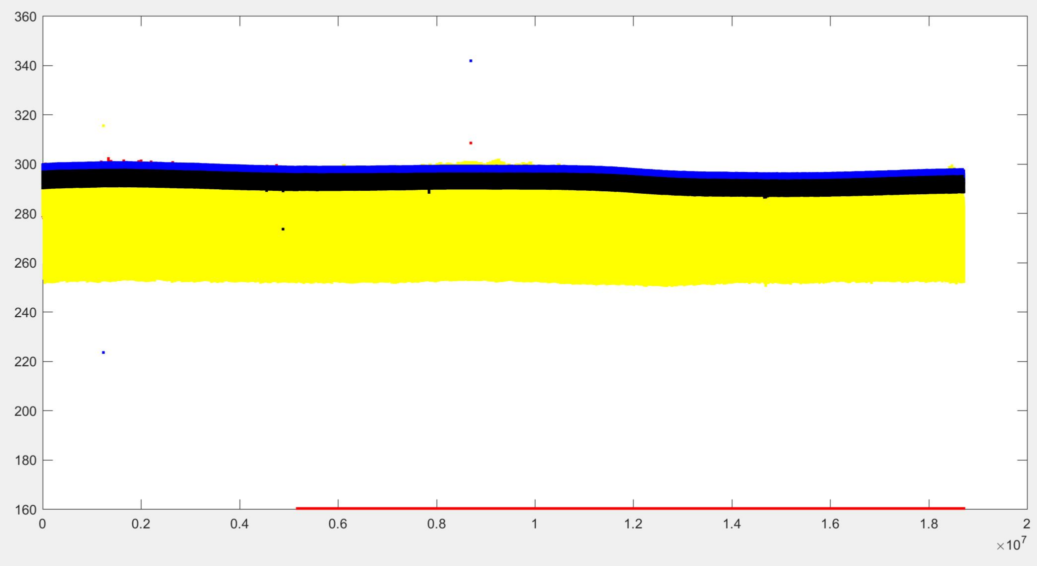
Problem:

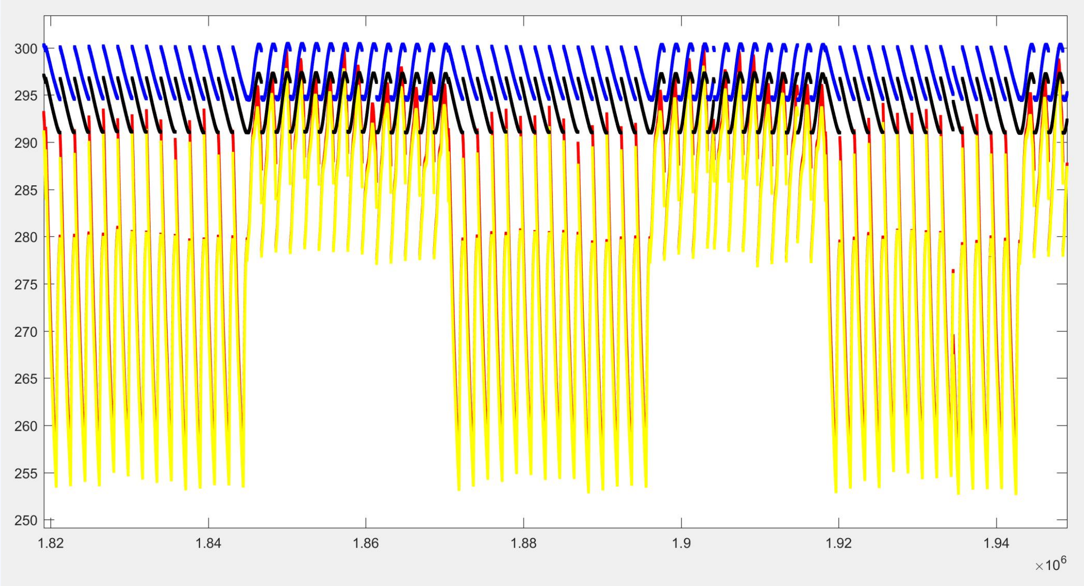
The temperature measurement of hot mirror lost function

{k,b}=f(T_hot mirror)

T_hot mirror ×

3.21 The AIRC results of FY-3D MWRI---- Microwave Band

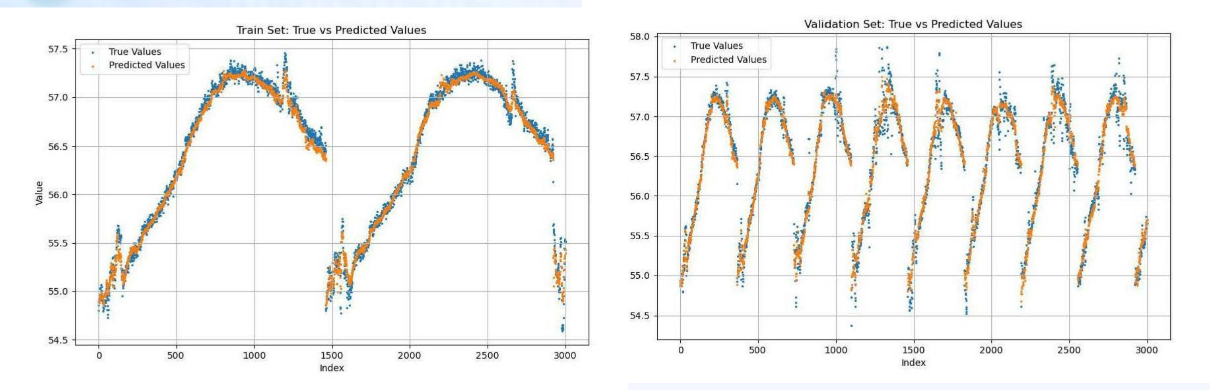




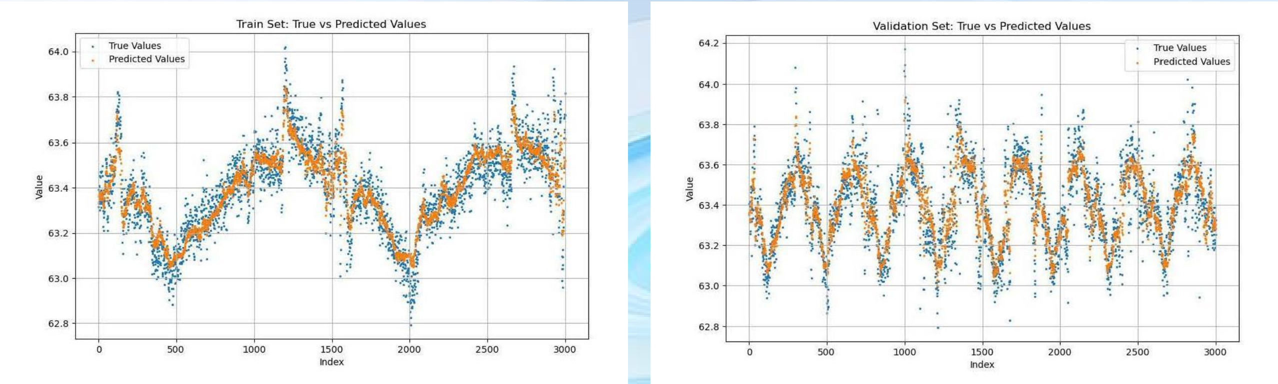
Temperatures of antenna and receiver

Magnified view of left fig
Short-term: noticeable fluctuations

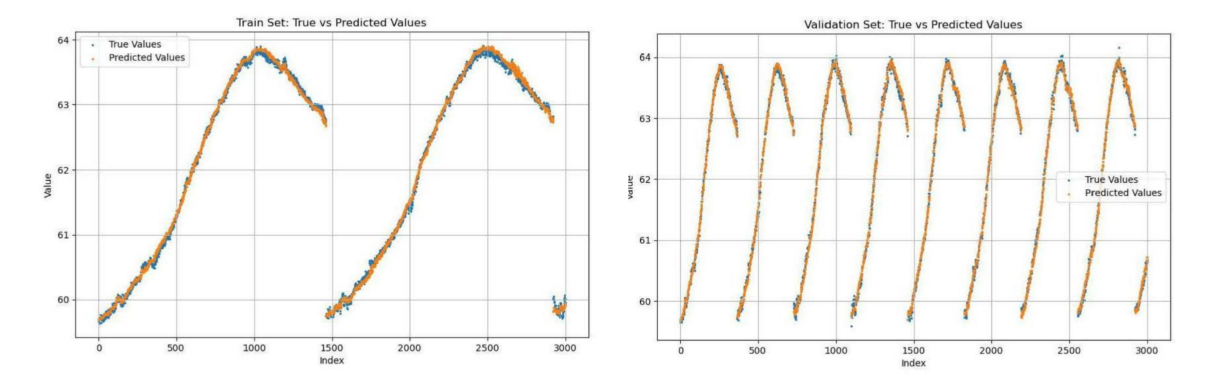
3.22 The results of MWRI----Comparisons of labels and outputs of RCNN



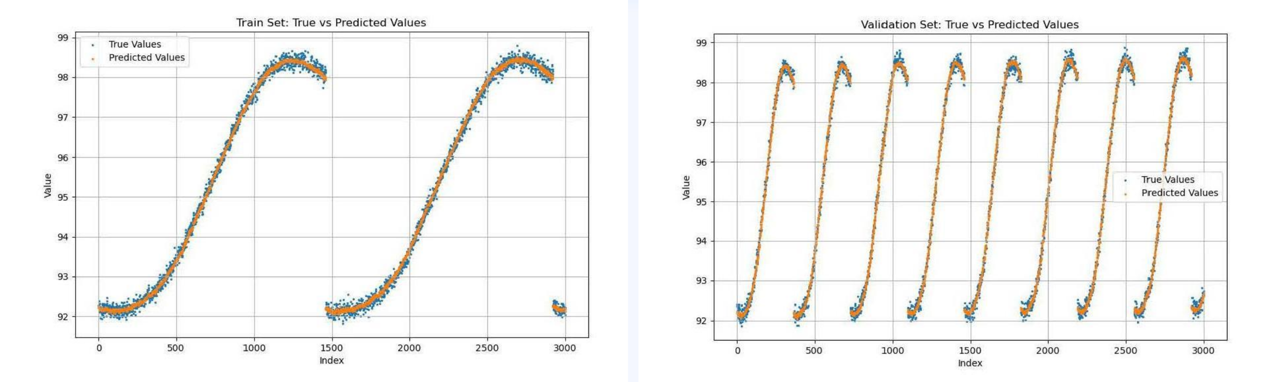
10GHz Labels and predictions of RCNN



18GHz Labels and predictions of RCNN



37GHz Labels and predictions of RCNN



89GHz Labels and predictions of RCNN

The maximum mean error of all the channels is less than 0.5K@300K

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3.1 Work Model 1—— Train RC-Net befor launch, application after launch

Source-**B**ased **R**adiometric **C**alibration
SBRC

BlackBody

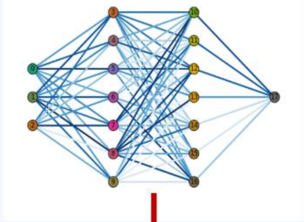
+

Sensor

+

Artificial **I**ntelligence **R**adiometric **C**alibration
AIRC

Radiometric Calibration Neural Network (RCNN)

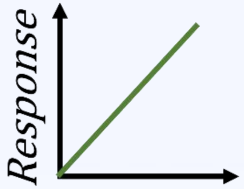


DN_{OBS}

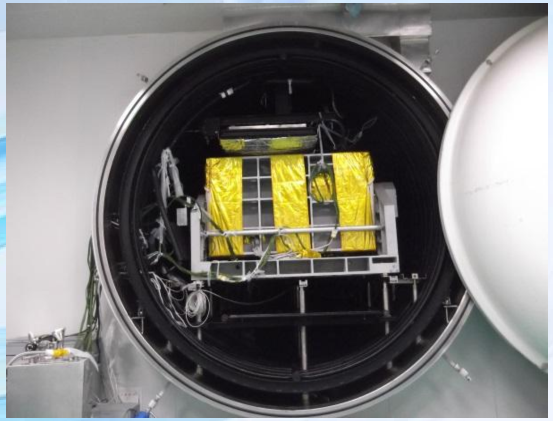
$Temperature_{INS}$

$$Slope = \frac{R_{BlackBody}}{DN_{BlackBody} - DN_{Space}}$$

$$Offset = -Slope \cdot DN_{Space}$$



$$\begin{Bmatrix} Slope \\ Offset \end{Bmatrix} = RCNN.out(Temperature_{INS})$$

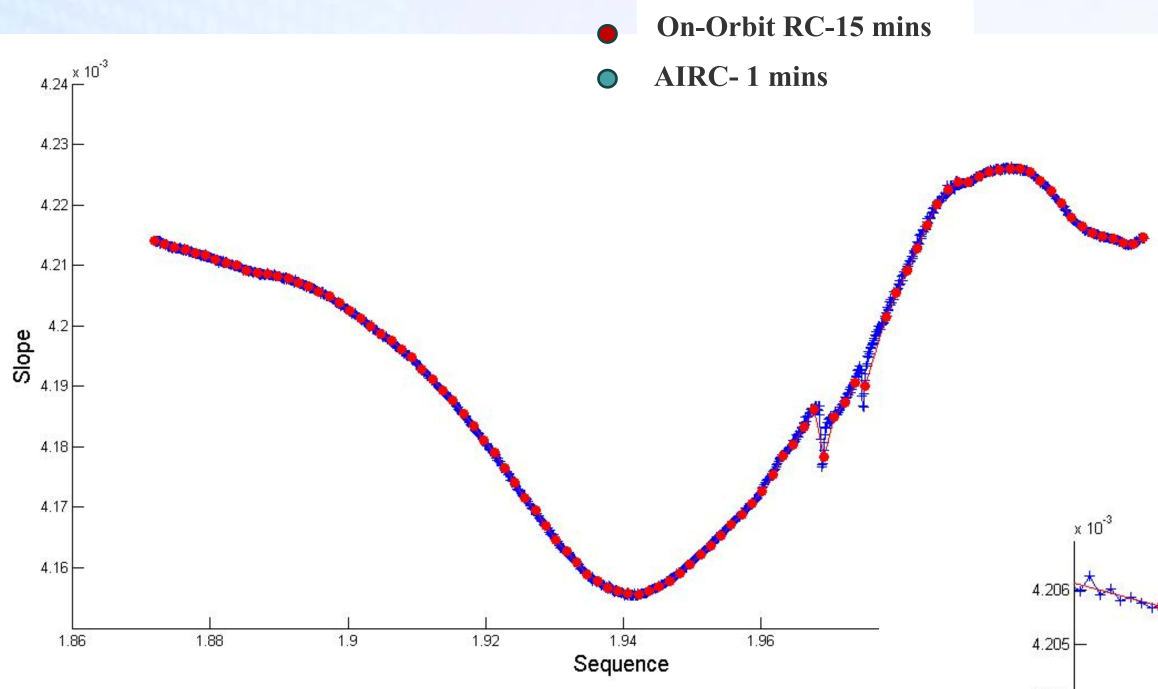


外壳温度(℃)	太阳屏温度(℃)	辐射板温度(℃)	一级温度(K)	二级温度(K)	二级制冷余量(mW)	辐冷筒温度(℃)
-107.04	-109.93	-112.55	109.25	80.17	20 探测器通电	-18.56
-107.14	-109.93	-112.67	108.98	78.22	0 探测器通电	-18.93
-100.89	-104.11	-108.45	112.19	83.45	40 探测器通电	-10.07
-99.60	-102.84	-107.53	113.17	88.30	92 探测器通电	-4.74
-99.68	-102.92	-107.53	113.22	88.29	100 探测器未通电	-4.08

Typical work mode:
Using pre-launch Calibration Result
To
train the RCNN

RC-Net：The relation between RC coefficients and work station

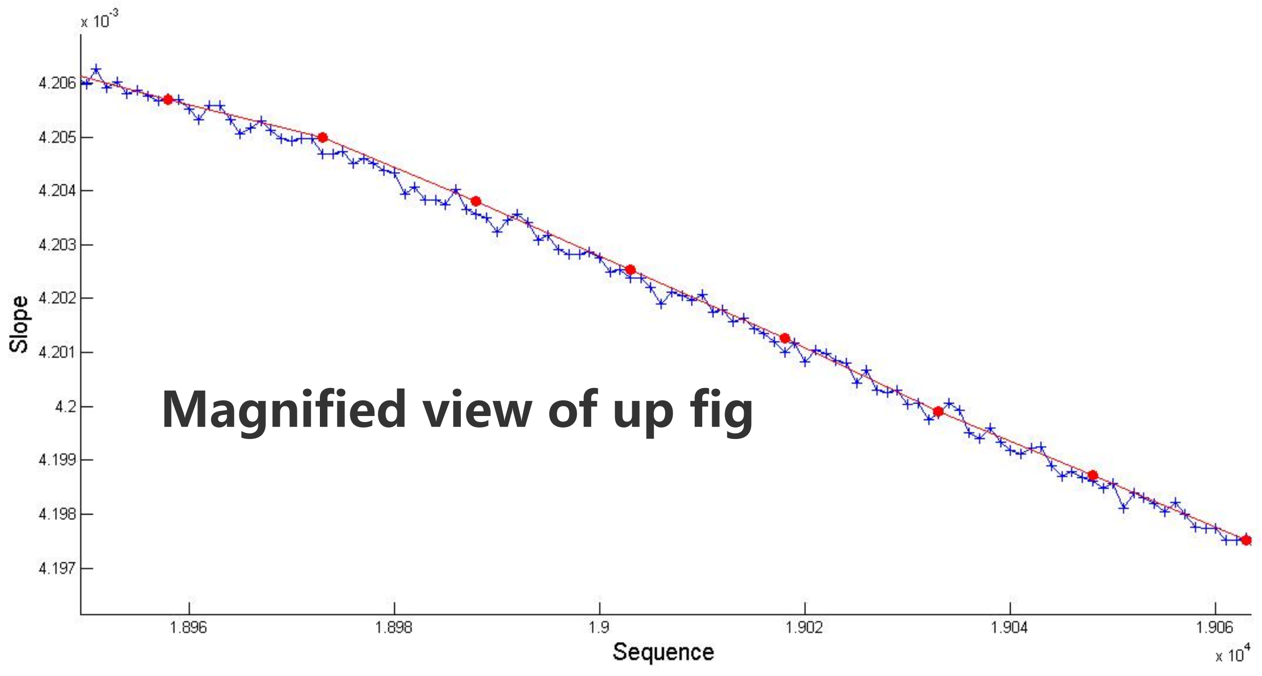
3.2 Work Model 2—— Together with on-board blackbody calibration



On-Board RC && AIRC

Red points： RC gains from blackbody every 15minutes

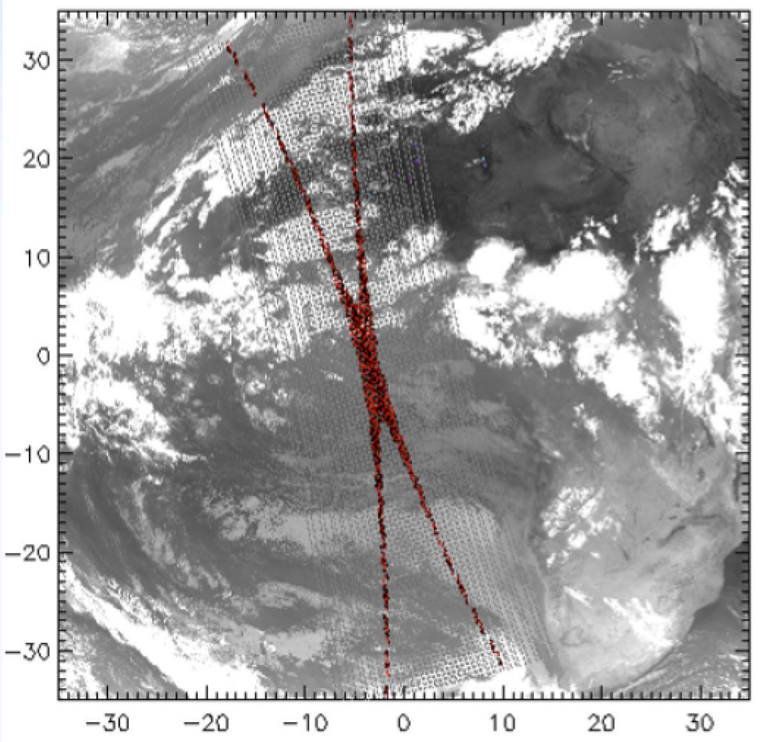
Blue points： RC gains from RCNN every 1 minutes

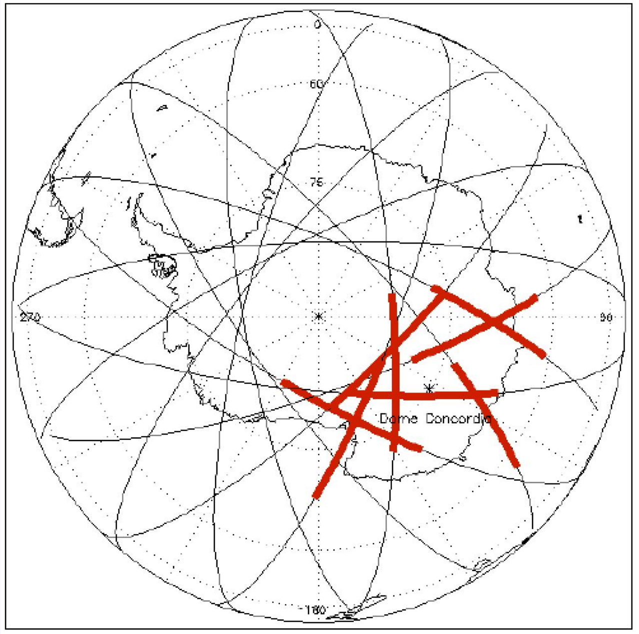


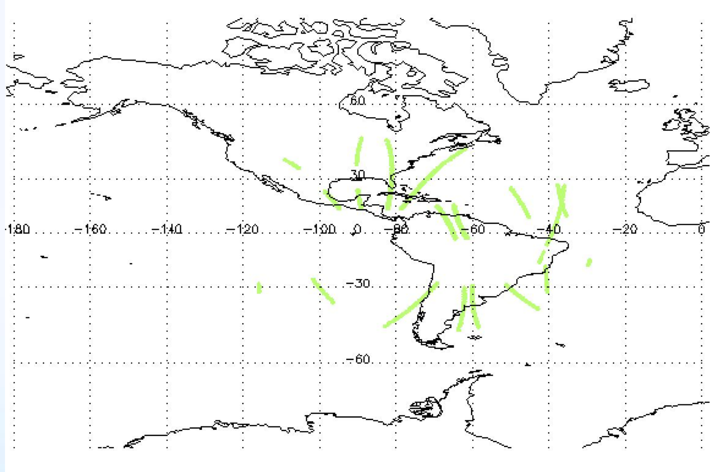
Magnified view of up fig

Adjust the RC coefficients along with the varations of temperatures of sensors

3.3 Work Model 3—— Together with GSICS







GSICS && AIRC

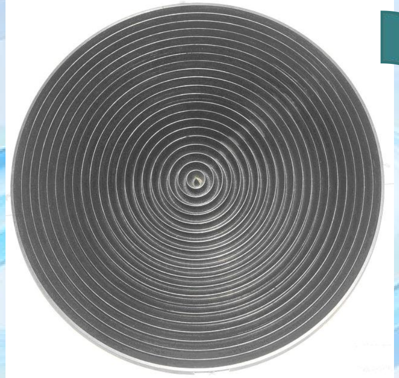
GSICS: Train RC-Net while SNO

AIRC: RCNN generates the operational RC coefficients

Especially: large-aperture sensors and small satellite without on-board blackbody

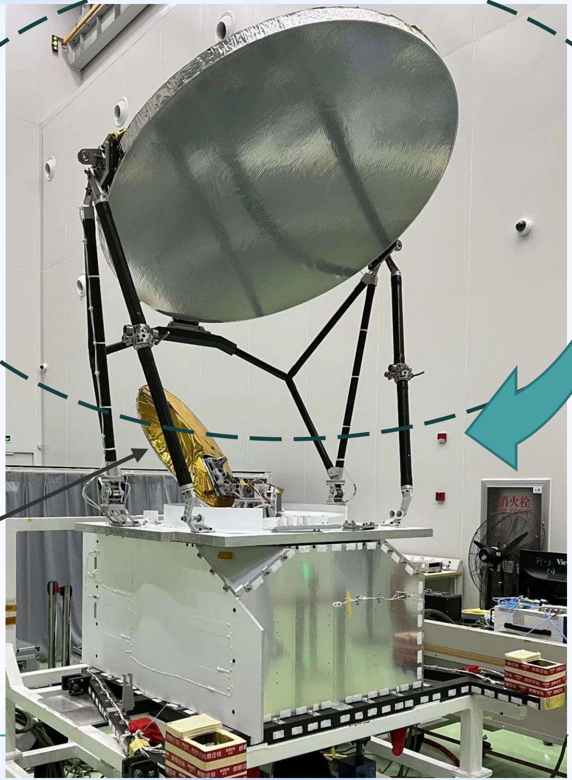
3.4 Work Model 4—— Train the RC-Net for partial-path RC while full-path RC

full-path RC



RCNN

The temperatures



partial-path RC

CONTENT
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4.1 Advantage of AIRC

1. Improve the operational RC accuracy

—— Any high accuracy calibration result could be used to train RCNN for generating high accuracy operational RC coefficients, and the RCNN accuracy could be less than 0.01K.

2. Make the operational calibration a greater timeliness

—— RCNN runs not only on ground-segment, but also on the satellite.

3. Save the weight and space for accommodating the on-board blackbody

—— Especially for the large-aperture sensors and small satellite.

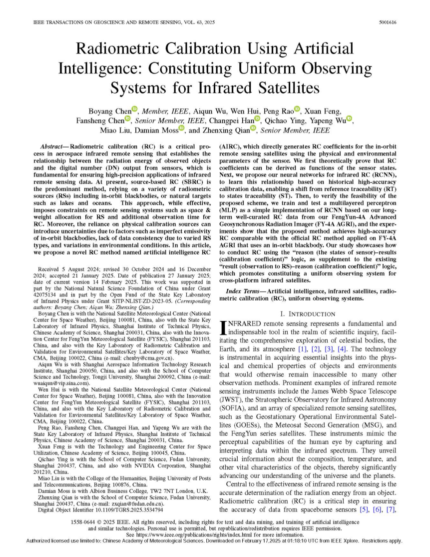
4. Save the launch cost for reducing the weight of blackbody

4.2 Progress (Article and Patent —Chinese) and Next Plan:

Infrared

- RC
- Navigation
- Digital Twin

microwave



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THE JOINT 2025 FENGYUN SATELLITE USER CONFERENCE

WeChat

扫一扫上面的二维码图案，加我为朋友。

Welcome anyone to discuss and apply AIRC

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