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THE 15TH ASIA-OCEANIA METEOROLOGICAL SATELLITE USERS' CONFERENCE (AOMSUC-15)
2025 FENGYUN SATELLITE USER CONFERENCE (2025 FYSUC)

Quantitative Applications of Satellite Remote Sensing
29 Oct. 2025, 15:20-15:35

The Test Setup and Method for Pre-launch Calibration of Infrared Sounder onboard FY-4 Satellites

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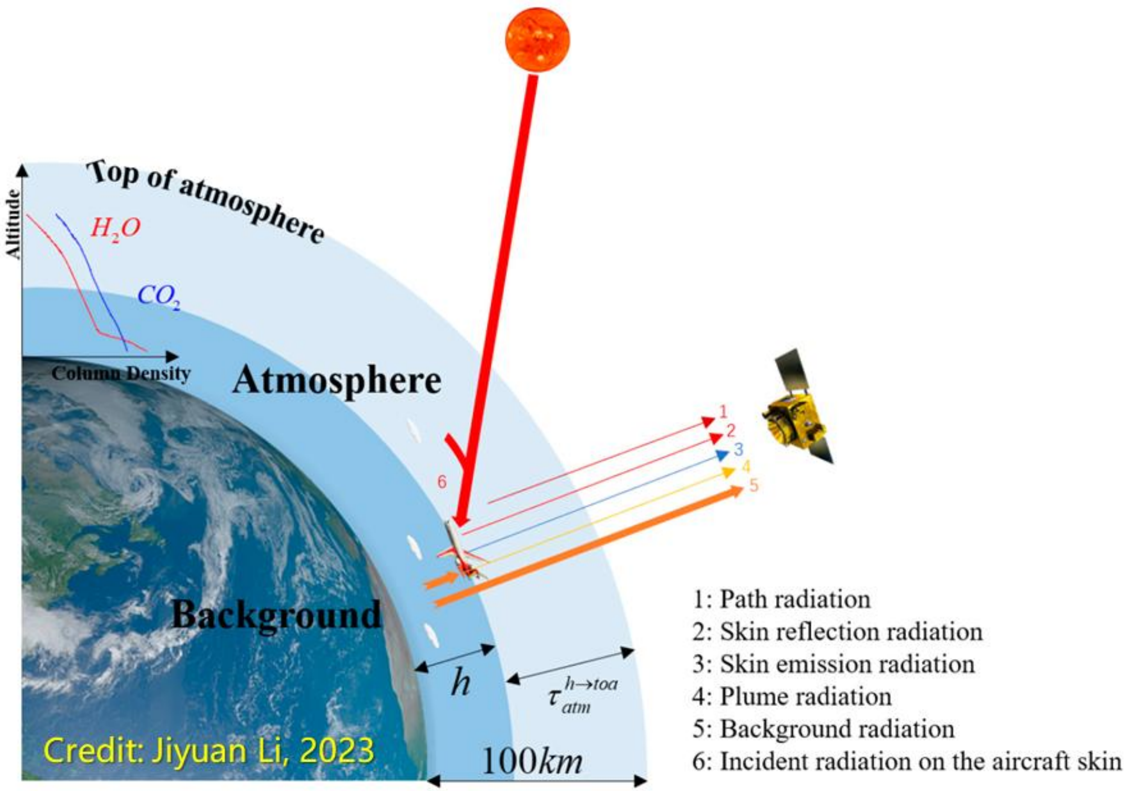
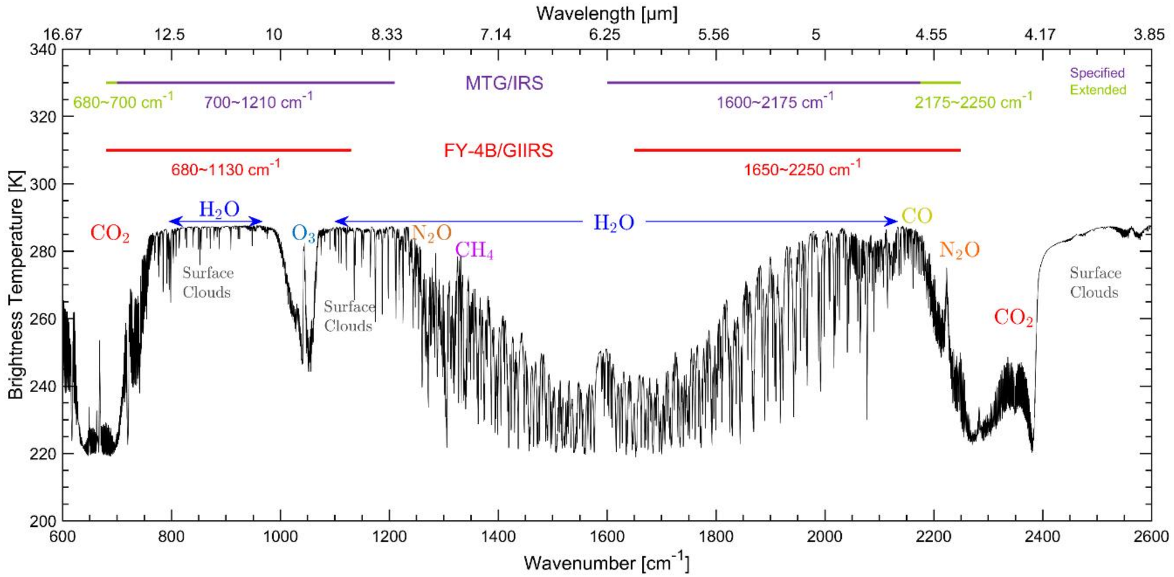
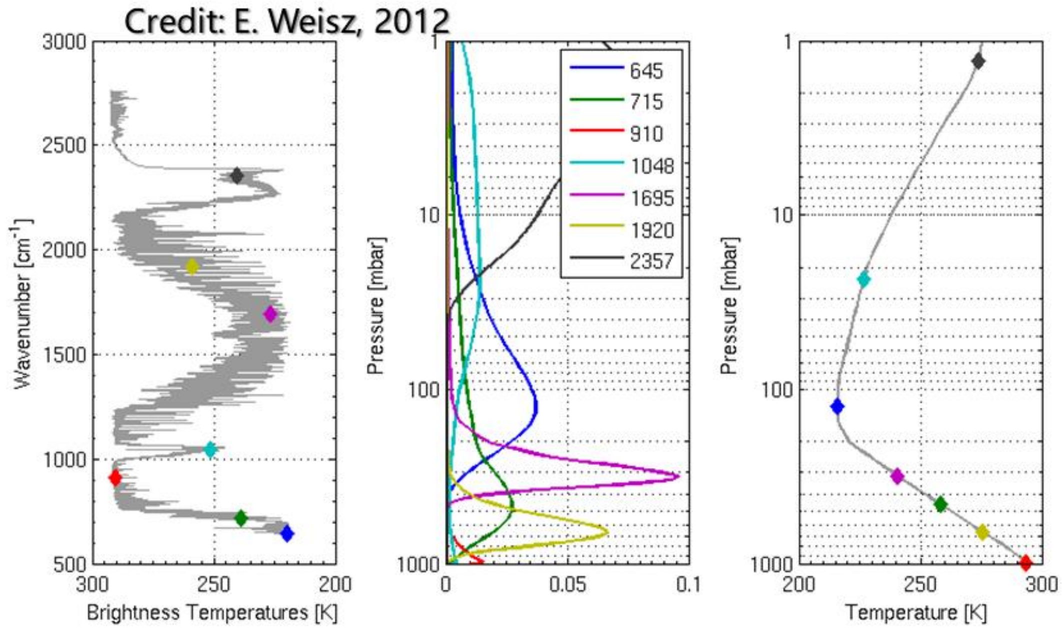
FY-4C/GIIRS on-orbit
courtesy of SISE

Oct. 27-31, 2025, Qingdao, China

1. Introduction of Hyperspectral Infrared Atmospheric Sounding







- ➢ The objectives of the Hyperspectral IRS are to:
- Provide information on vertical structure of water vapor, temperature and wind at high spatial, temporal, and vertical resolution (4 km, 1 h, 1 km).
- Support air chemistry and air quality applications (O3, CO).
- Support regional climate variable records (LST/SST).

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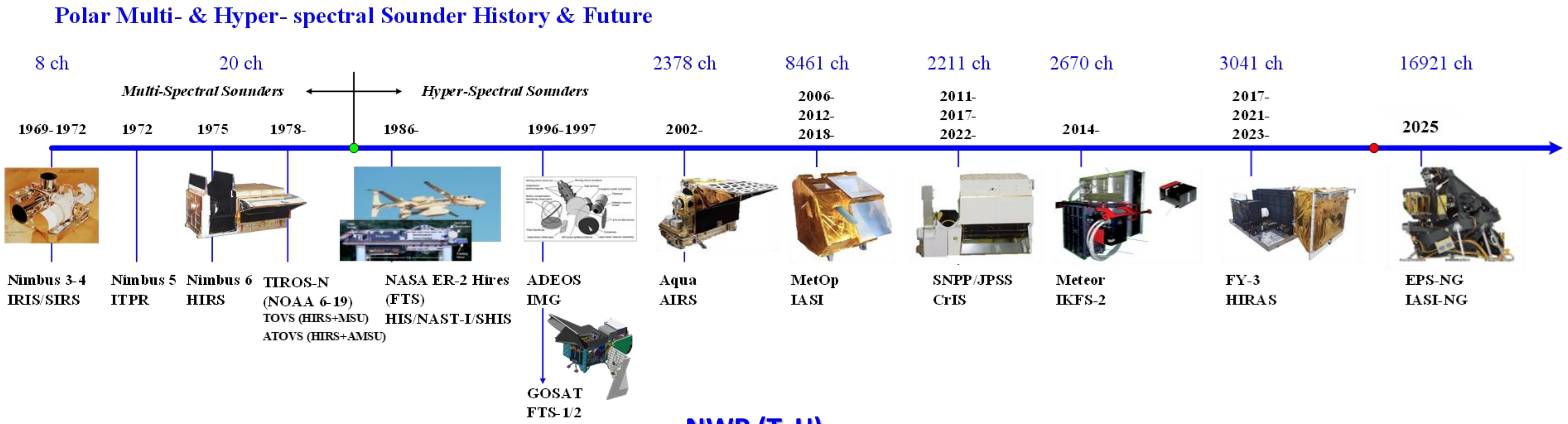
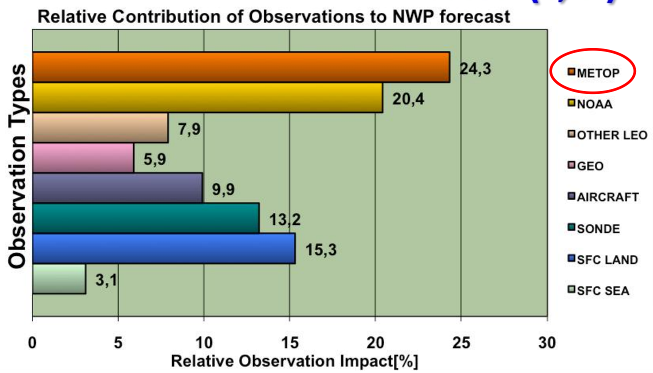
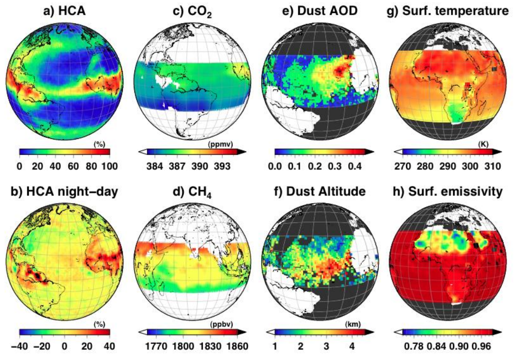


MetOp/IASI

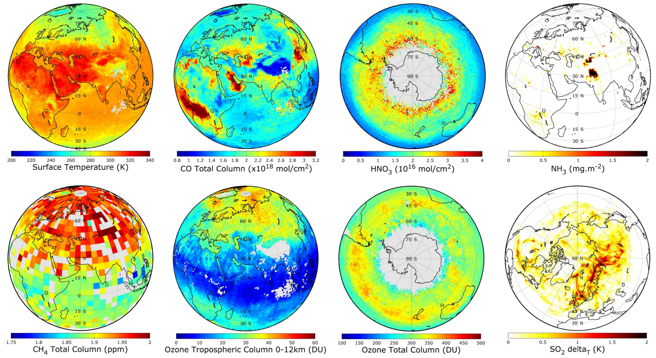
NWP (T, H)



AC&AQ (O3, NH3, CH4,CO)

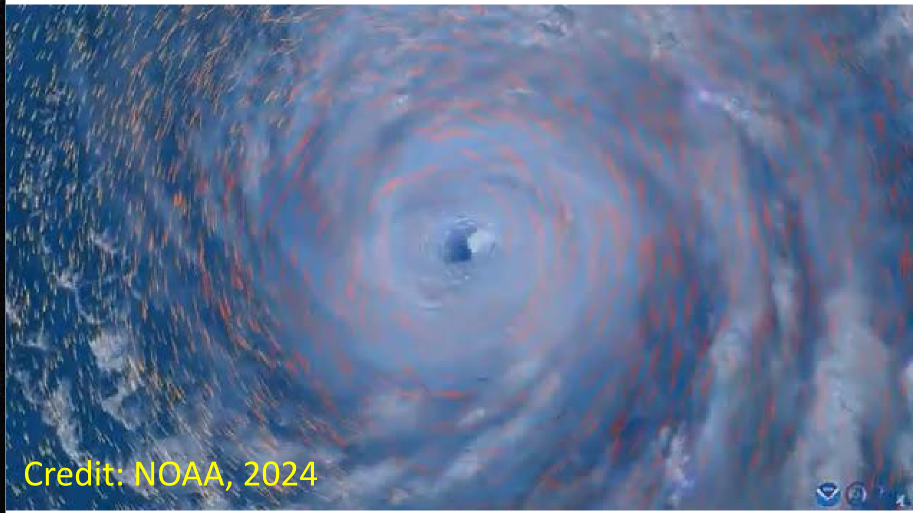


Climate Record (LST, SST)



1. Introduction of Hyperspectral Infrared Atmospheric Sounding

- Detector arrays: 128×128;
- Spec. bands: 685~1130 cm^{-1}, 1650~2250 cm^{-1};
- Spec. Res.: <0.6 cm^{-1};
- Spatial Res.: 4 km × 4 km per pixel;
- Dwell Area: 512 km × 512 km;
- Time interval: 1~11 s;



4-D Wind、Temperature、Water vapor

- In 2000-2006, NASA GIFTS is the combination of the Fourier transform spectrometer and the large area format detector array (i.e., an imaging interferometer), and the geo. satellite platform.
- In 2006, GIFTS was cancelled due to budgetary constraints.

- The Hyper-spectral imaging interferometer concept: **GIFTS**

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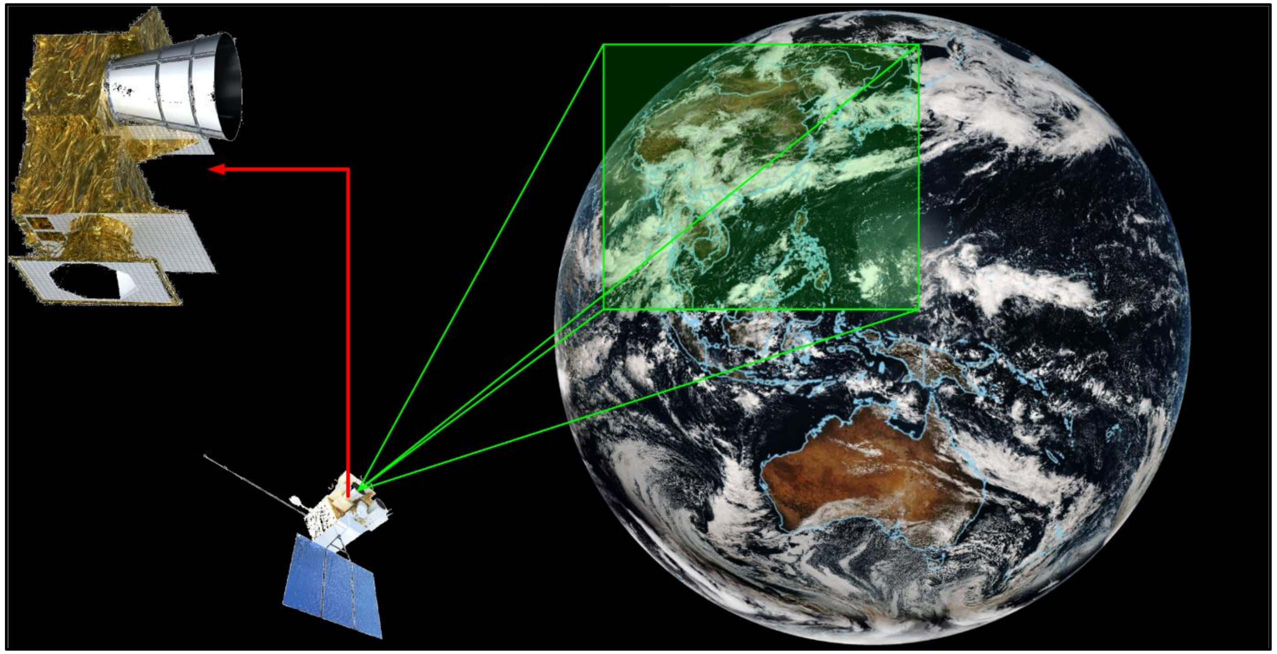
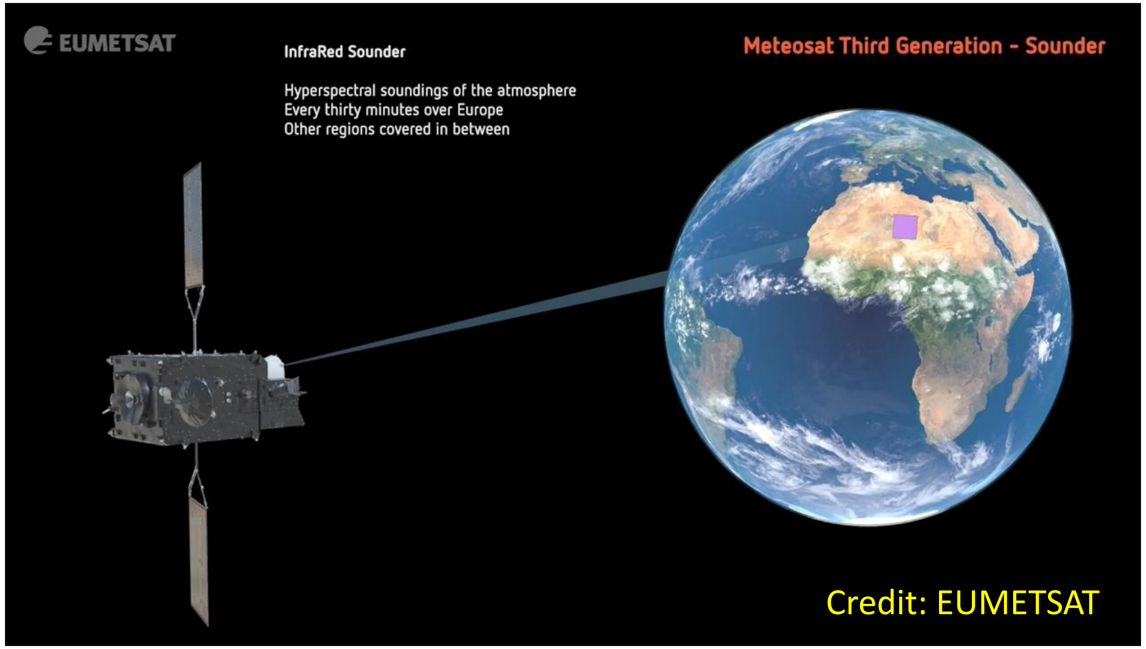
1. Introduction of Hyperspectral Infrared Atmospheric Sounding





- ➢ The Geo. IRSs currently in orbit
- FY-4A/GIIRS was launched on December 11th, 2016,
- FY-4B/GIIRS was launched on June 3rd, 2021,
- MTG-S1/IRS was launched on July 1st, 2025,
- FY-4C/GIIRS is scheduled to be launched on December 27th, 2025.
- ➢ Unlike the scientific demonstration of FY-4A satellite, the observations of FY-4B and followings will be used in the operational models.

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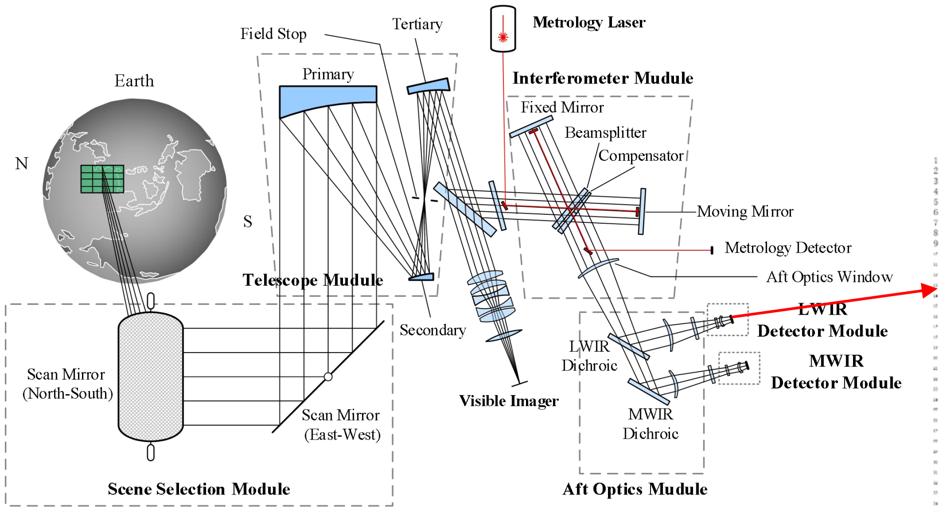
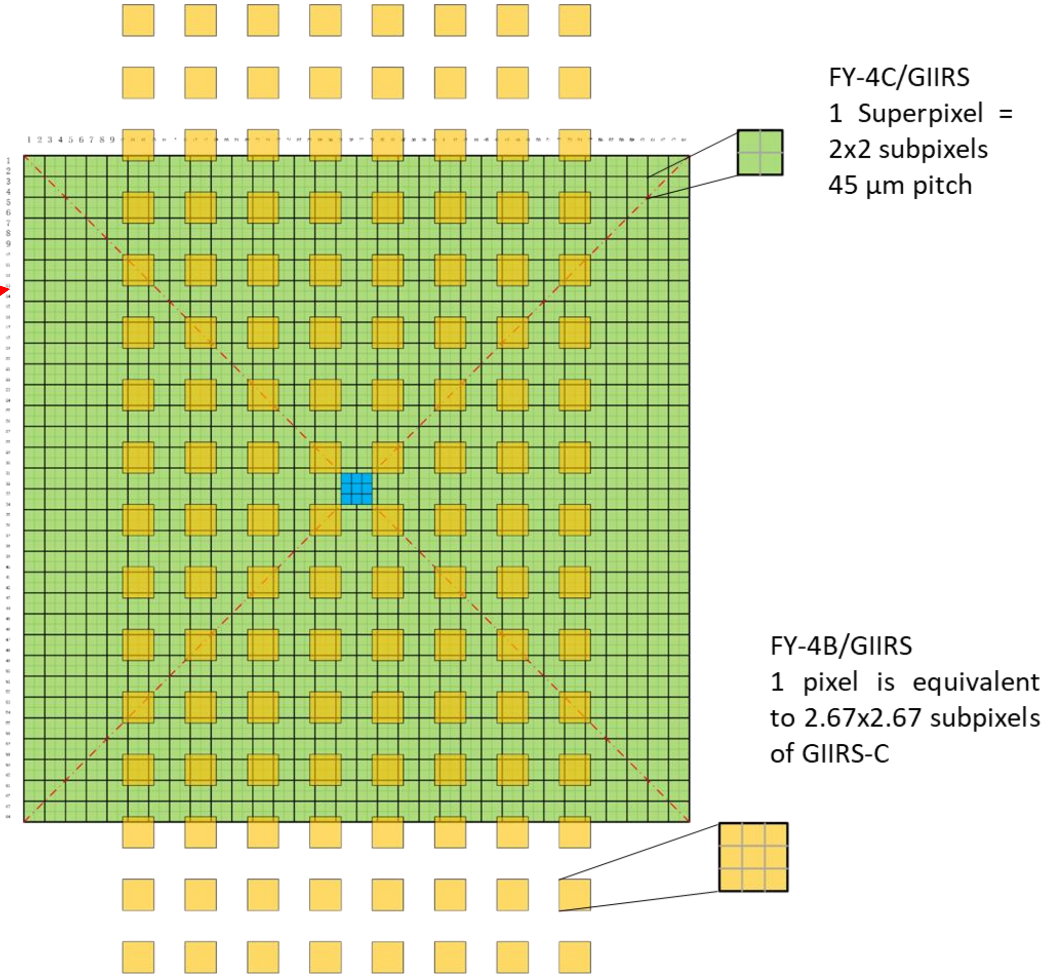
2. FY-4C/GIIRS Update



Requirement	FY-4B	FY-4C
Spectral Range	LWIR: 680~1130 cm^{-1} MWIR: 1650~2250 cm^{-1}	LWIR: 650~1130 cm^{-1} MWIR: 1650~2250 cm^{-1}
Spectral Sampling	0.625 cm^{-1}	0.625 cm^{-1}
Noise (NEdR)	LWIR: less than 0.5 r. u. MWIR: less than 0.1 r. u.	LWIR: less than 0.5 r. u. MWIR: less than 0.1 r. u.
Spectral accuracy	7 ppm	5 ppm
Radiometric accuracy	0.7 K	0.5 K
Detector Matrix	16×8, sparse layour	64×64, FPA
IR Spatial Sampling	12 km @ s.s.p.	8 km @ s.s.p.
Dwell Duration	10.4s for a 384km × 192km area	~10s for a 256km × 256km area
Observation Coverage	China and its surroundings @ 105°E (2024.02~now)	China and its surroundings @ 133°E (undetermined)
Repeat Cycle Duration	1.5 hours	~1 hour
VIS Spatial Sampling	1 km @ s.s.p.	0.5 km @ s.s.p.

r. u.: radiance unit, mW/[m^2·sr·cm^{-1}]
s.s.p.: sub-satellite point



IR detector of GIIRS-C v.s. GIIRS-B

- The main change of GIIRS-C is that the detector in each band is updated from the 16×8 pixel with sparse layout of GIIRS-B to a 64×64 pixel layout (FPA).

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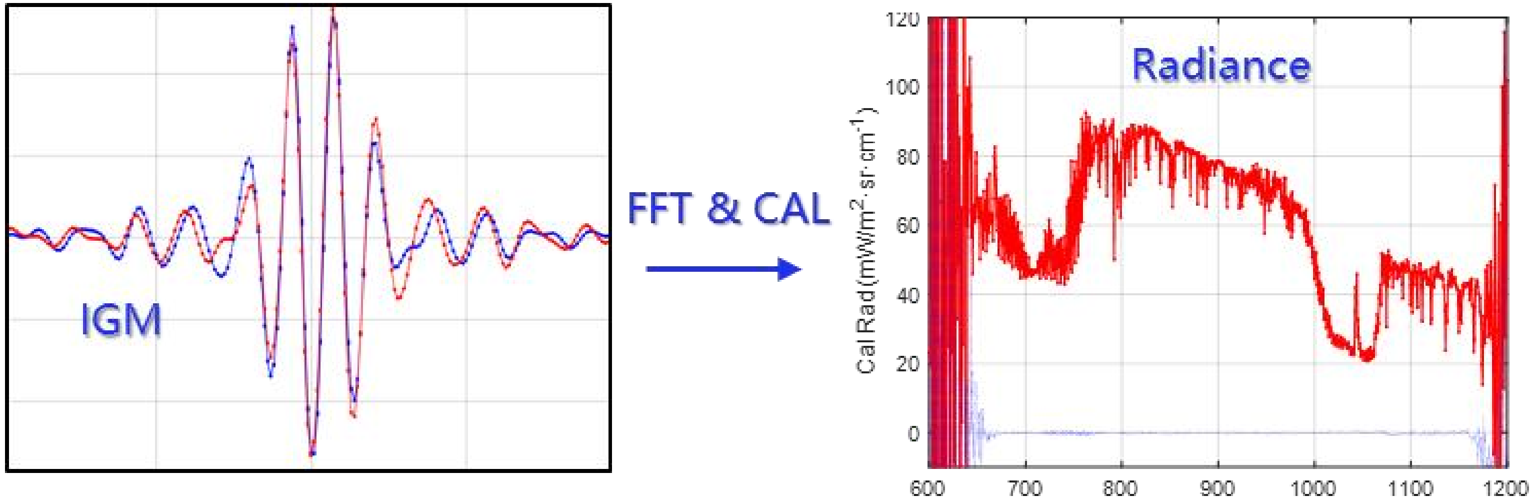
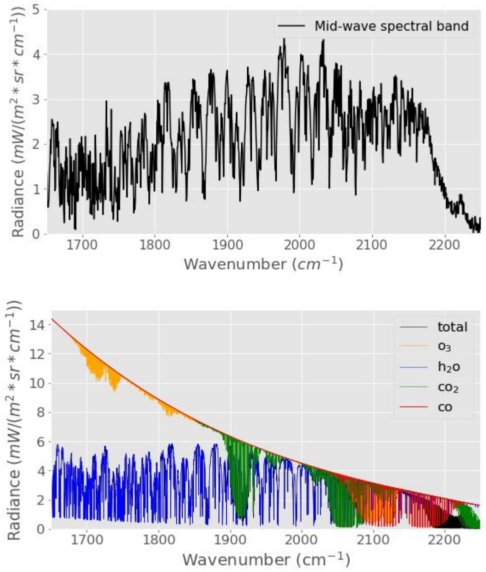
3. FY-4/GIIRS Preflight Test Campaign



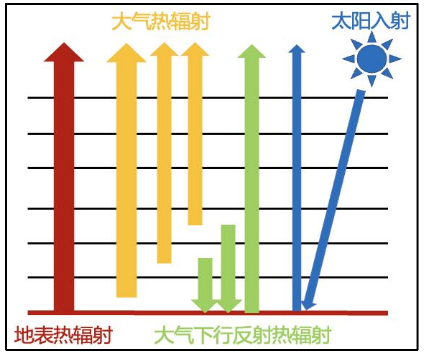
- The interferograms are convert to raw spectra by FFT, and then the raw spectra are further calibrated to radiance.

Spectra measurement



Retrieval system

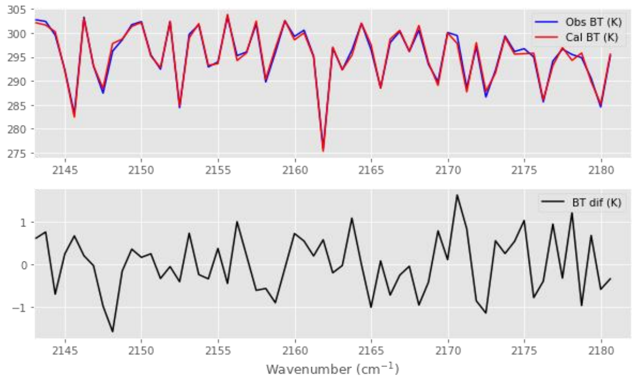
Radiative transfer forward model



Optimal estimation inverse model

$$\chi^2 = [\boldsymbol{y} - \mathbf{F}(\boldsymbol{x}, \boldsymbol{b})]^T \mathbf{S}_\varepsilon^{-1} [\boldsymbol{y} - \mathbf{F}(\boldsymbol{x}, \boldsymbol{b})] + (\boldsymbol{x} - \boldsymbol{x}_\mathrm{a})^T \mathbf{S}_\mathrm{a}^{-1} (\boldsymbol{x} - \boldsymbol{x}_\mathrm{a}),$$

Spectral fit



CO + other auxiliary parameters (H2O, SurfT, AirT)

- The retrieval model based on the radiative transfer model also requires high-precision calibration of the observations.

Credit: Z. Zeng, PKU, 2023

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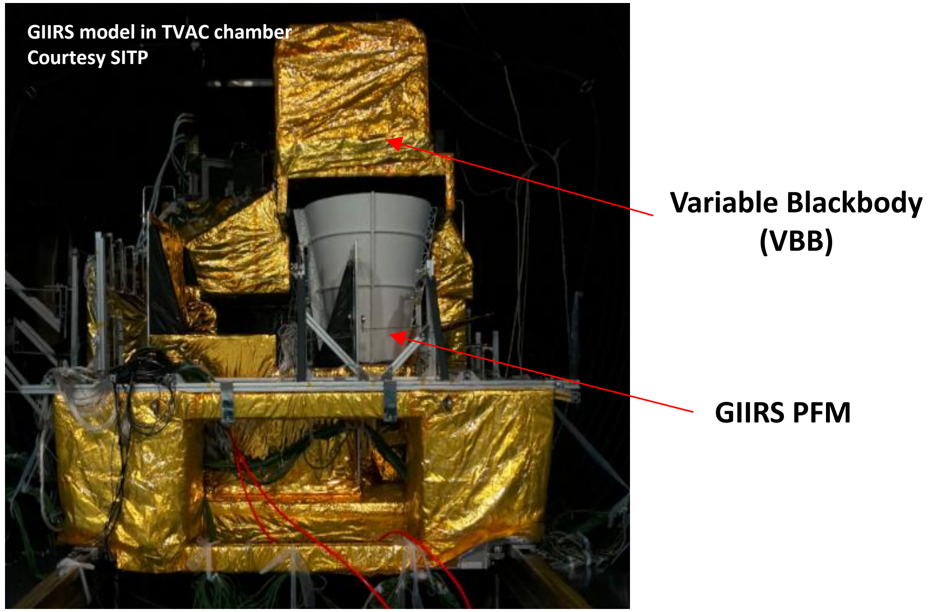
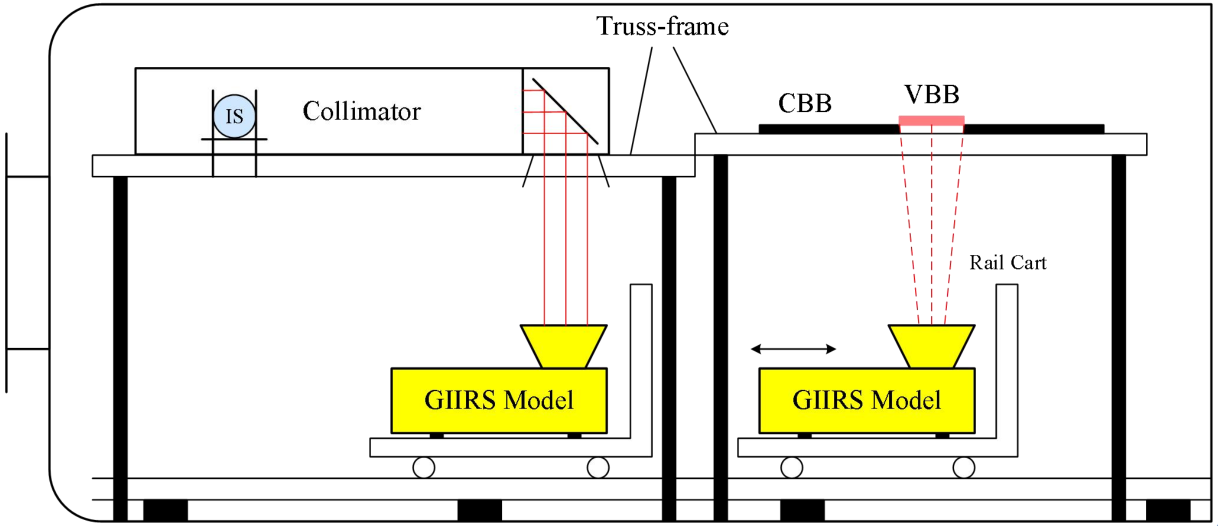
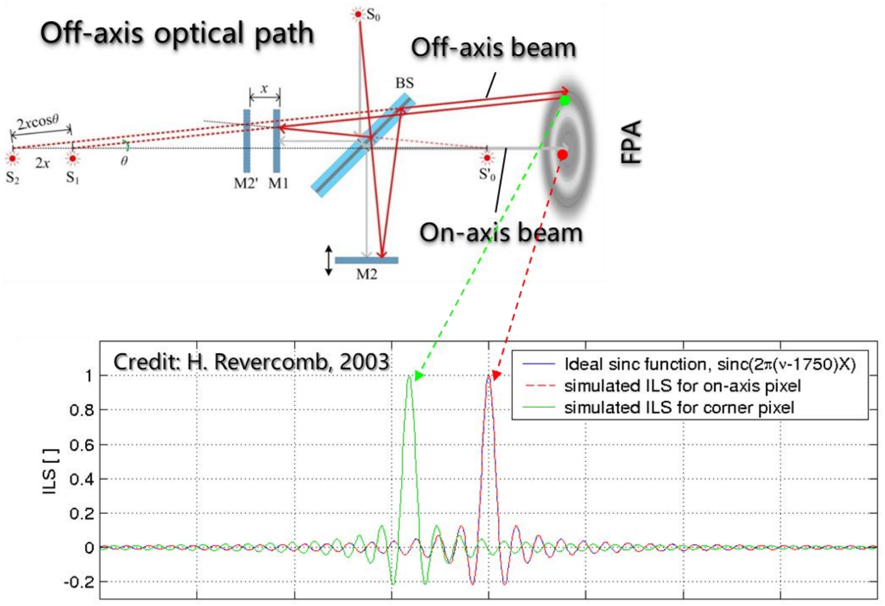
3. FY-4/GIIRS Preflight Test Campaign

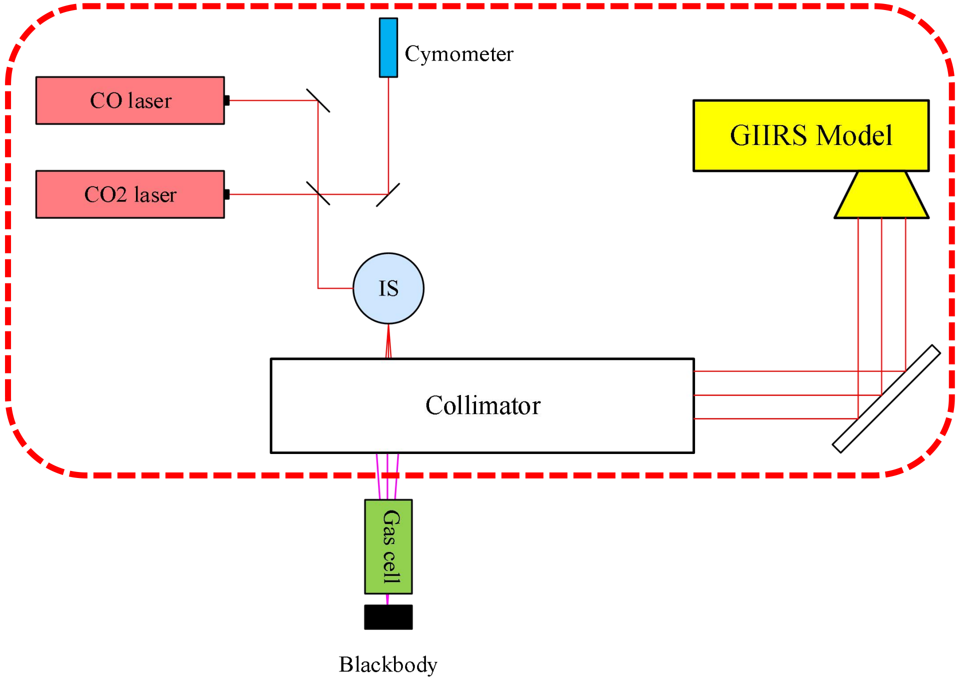


- The prelaunch test campaign of GIIRS proto-flight-model was completed by SITP in February, 2020. The instrument and ground support equipments were located inside the thermal vacuum (TVAC) chamber. The most important tests in TVAC are geometric optical test, spectral and radiometric performance tests.



4. FY-4/GIIRS Spectral Calibration





- In spectral calibration tests, the setup consists of two quasi-monochromatic lasers with a metrology calibrated cymometer, one Integrating sphere, two separate gas-cells filled with ammonia and carbon monoxide, a background blackbody, and a collimator.
- The 10.6μm CO_2 laser was used to measure the LWIR instrument line shape (or ISRF), and the 5.4μm CO laser was used to measure the MWIR instrument line shape.
- The Gas-Cell measurements are used to obtain the self-apodization correction coefficients and further to evaluate the spectral calibration accuracy.

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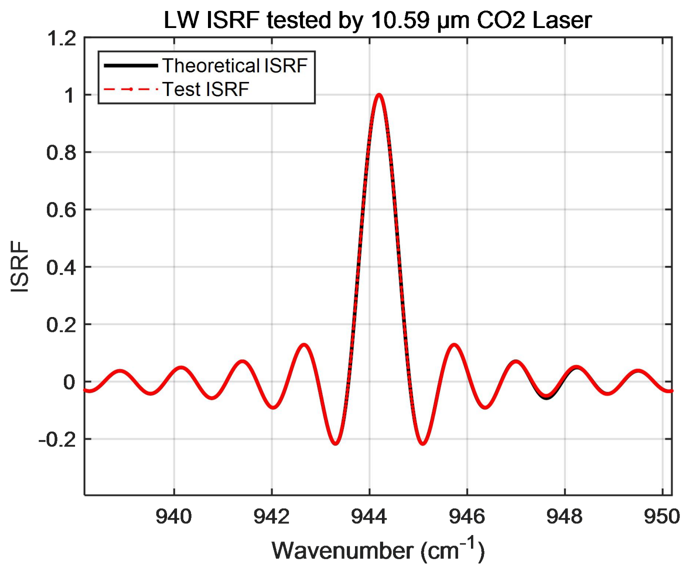
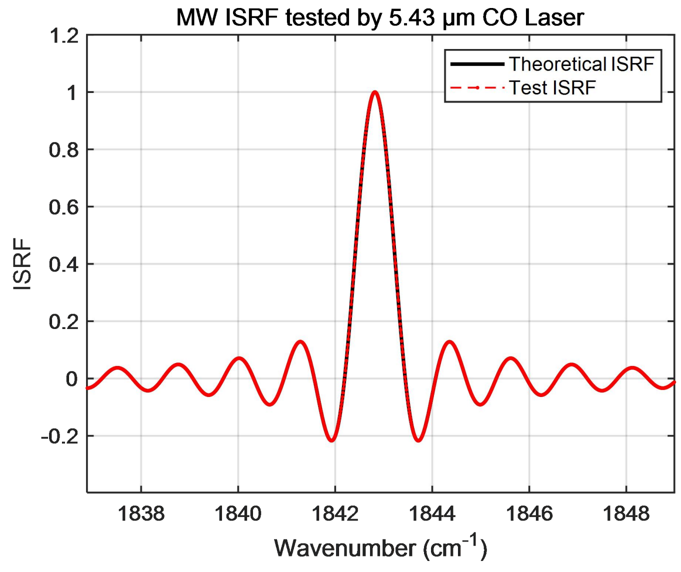
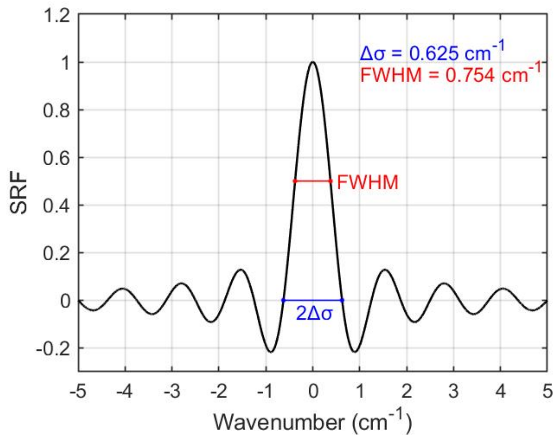
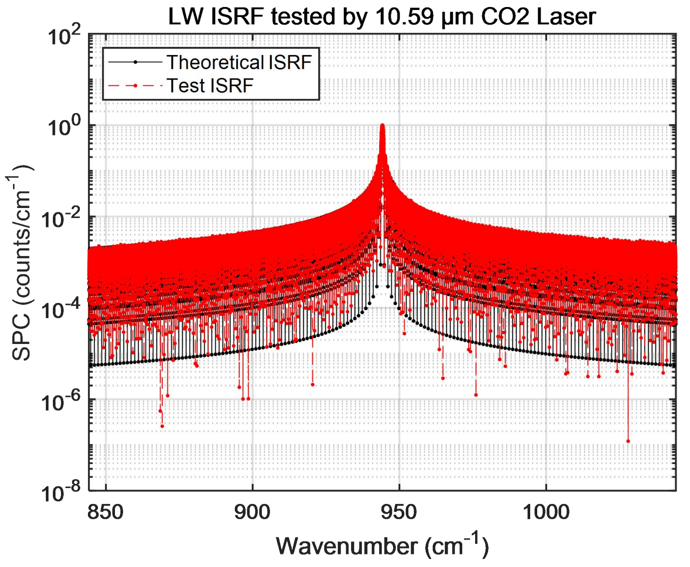
4. FY-4/GIIRS Spectral Calibration

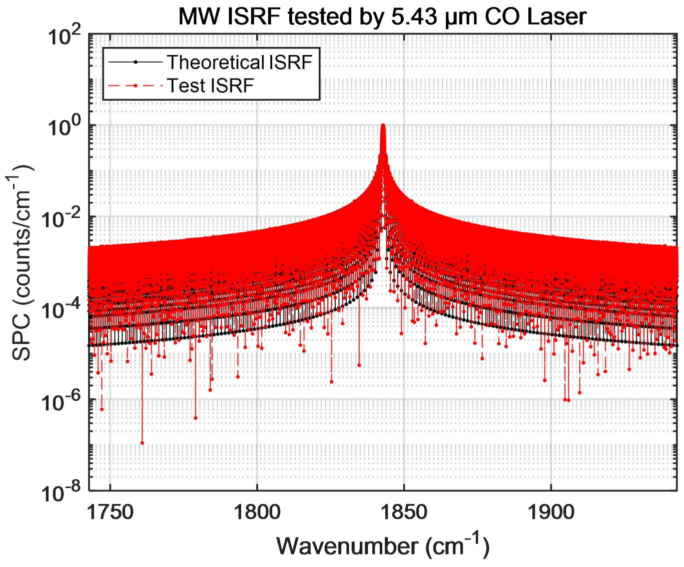


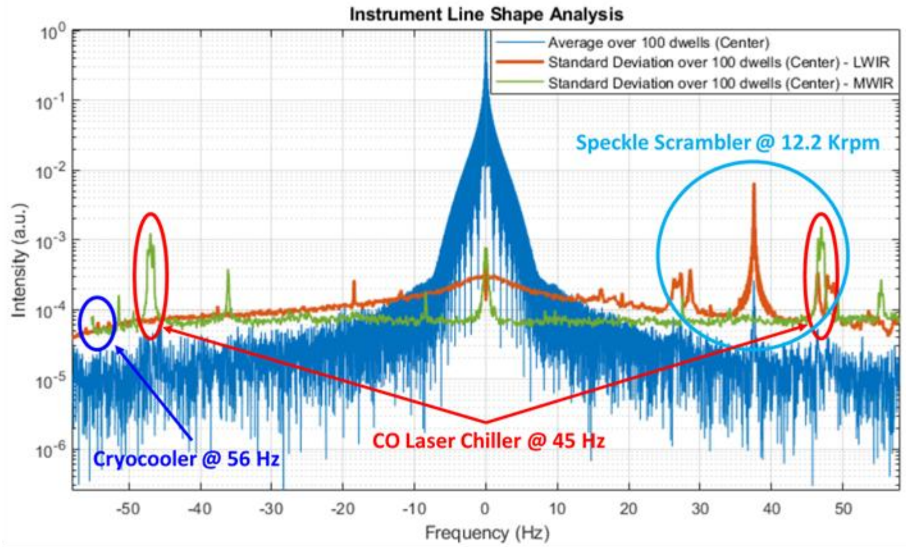




- The ISRF of an ideal FTS with SR 0.625 cm^{-1}



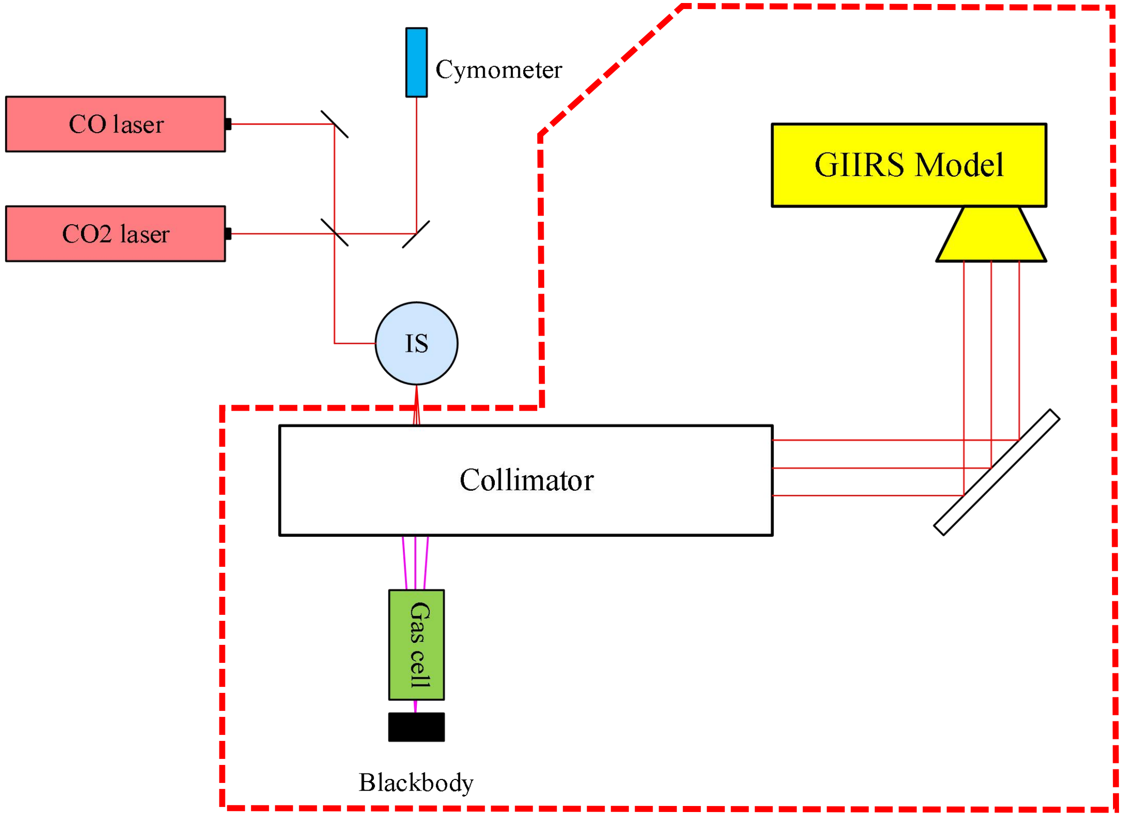




Credit: Francesc Lucas Carbo, OHB, 2023

- The LW/MW ISRF of GIIRS

4. FY-4/GIIRS Spectral Calibration



$$\tau_{gas} = \frac{C_{FTH} - C_{FTC}}{C_{ETH} - C_{ETC}}$$

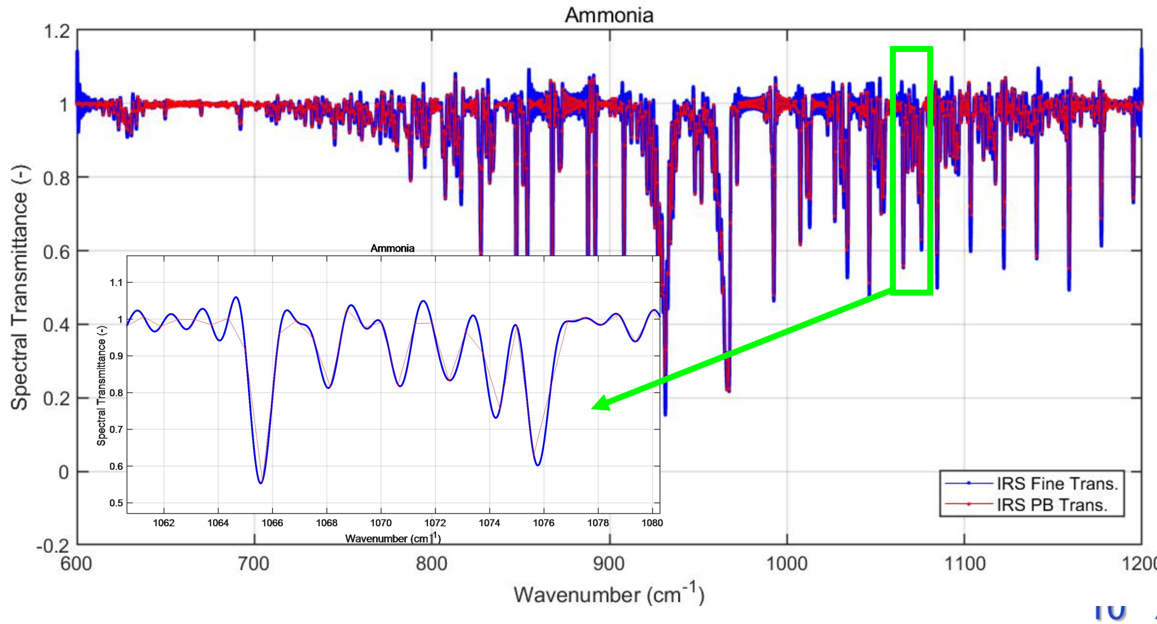
τ: gas transmittance spectra

C_{FTH}: spectra of cell full of gas with hot blackbody

C_{FTC}: spectra of cell full of gas with cold blackbody

C_{ETH}: spectra of cell empty of gas with hot blackbody

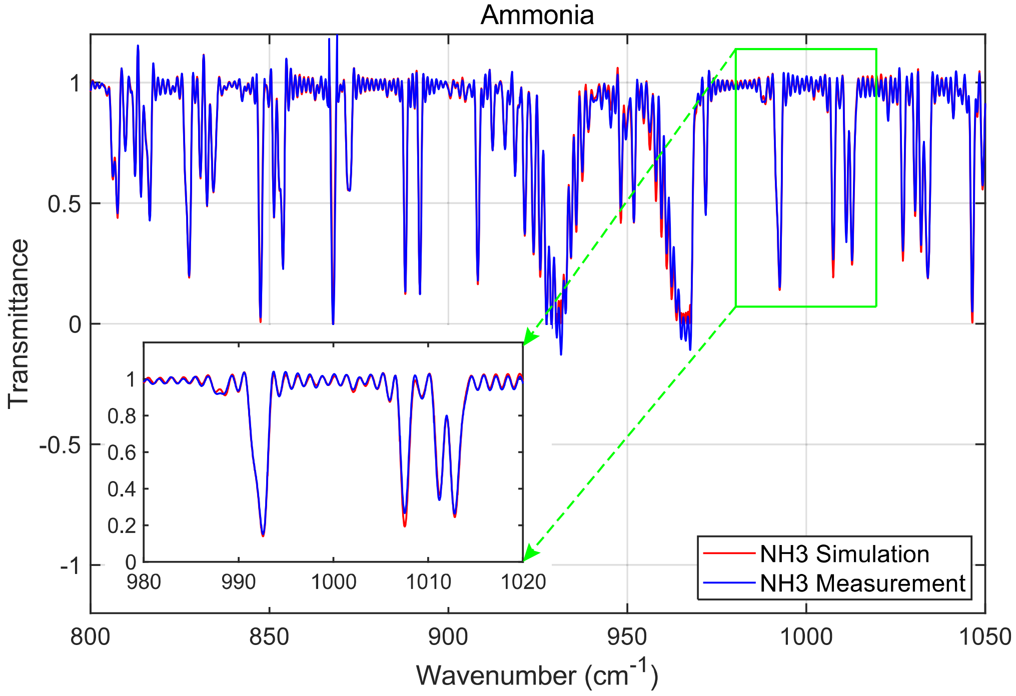
C_{ETC}: spectra of cell empty of gas with cold blackbody

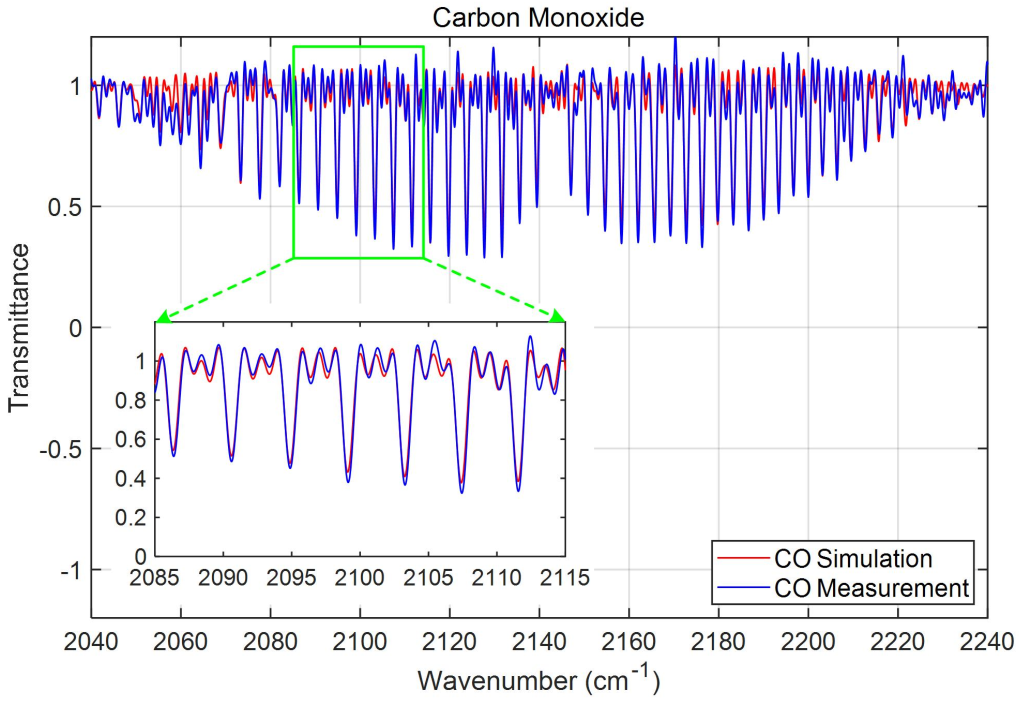


- The Gas-Cell measurements are used to obtain the self-apodization correction coefficients and further to evaluate the spectral calibration accuracy.

$\delta\sigma_{norm}$: 0.625 cm-1
$\delta\sigma_{fine}$: 0.0001 cm-1
0.1 ppm @ 900 cm-1

4. FY-4/GIIRS Spectral Calibration



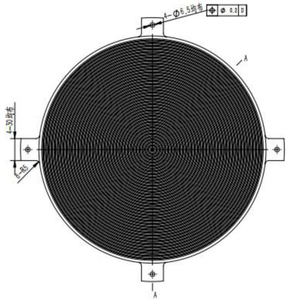


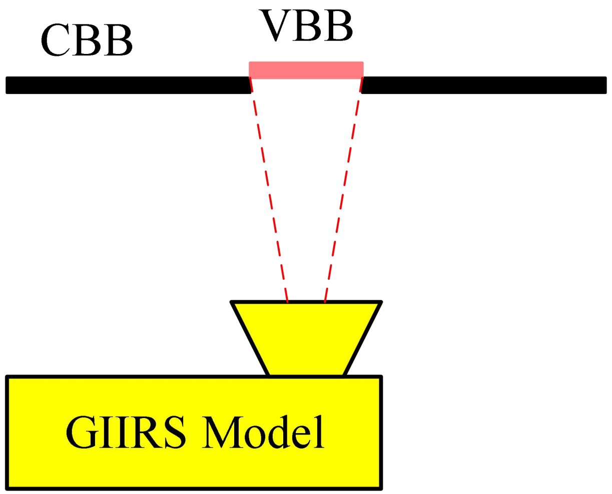
Comparison of calibrated NH3/CO spectrum and the LBLRTM simulations

$\rho = \delta\sigma/\sigma_0 = 5\text{ppm}$

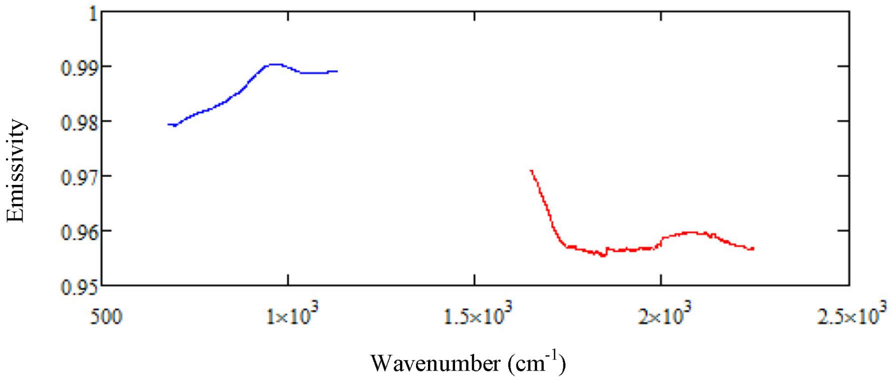
- The reference spectrum of ammonia/carbon monoxide in gas-cell is simulated by LBLRTM model. Then the self-apodization factors were estimated by comparison of measured spectrum and LBLRTM simulations. After SA correction and spectral re-sampleing, the spectral accuracy is less than 5 ppm.
- Although the SA correction coefficients were estimated from gas-cell tests, they were still adjusted based on the actual atmospheric spectral lines after GIIRS launch.

5. FY-4/GIIRS Radiometric Calibration





Internal Calibration Target (ICT) is a internal BB with 300K.



Emissivity of VBB

- GIIRS radiometric calibration is based on linear calibration methodology. Then, two reference views are used for radiometric calibration. one is onboard blackbody (or ICT), the other is cold space.
- The radiometric calibration setup consists of a cold blackbody (CBB) and a variable blackbody (VBB). The VBB is simulated as the Earth scene with view field being as same as that GIIRS view the Earth in orbit. It is based on circular concentric grooves, and the emissivity in LWIR is better than 0.98, and in MWIR is better than 0.95.

Variable Temperatures of VBB in TVAC Chamber

#	T_{VBB}, K	T_{CBB}, K	T_{ICT}, K
1	180.15	98.98	300.79
2	190.15	79.79	300.24
3	200.15	78.80	300.21
4	210.15	78.66	300.22
5	220.15	78.51	300.22
6	230.15	78.31	300.20
7	235.15	78.47	300.26
8	240.15	78.93	300.38
9	245.15	78.13	300.53
10	250.15	77.95	300.65
11	255.15	77.93	300.79
12	260.15	77.90	300.92
13	265.15	77.86	301.02
14	270.15	77.87	301.19
15	280.15	76.99	301.30
16	290.15	76.92	301.43
17	295.15	76.97	301.54
18	300.15	77.86	301.93
19	305.15	77.73	301.99
20	310.15	77.58	301.99
21	315.15	77.61	302.04
22	320.15	77.60	302.08

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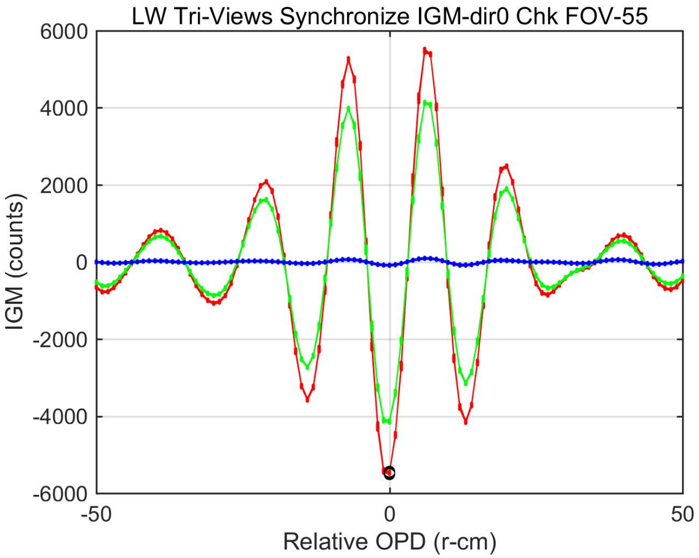
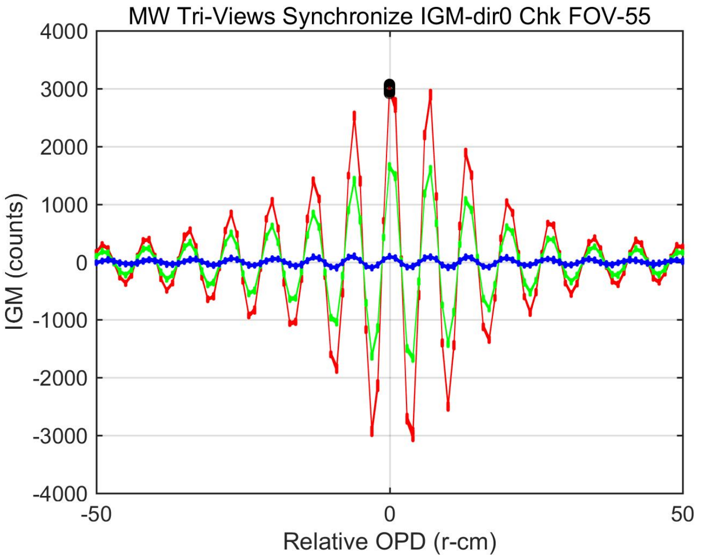
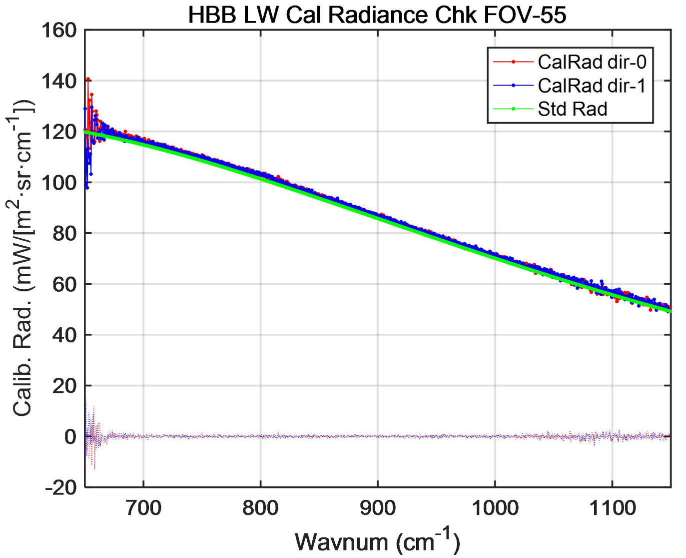
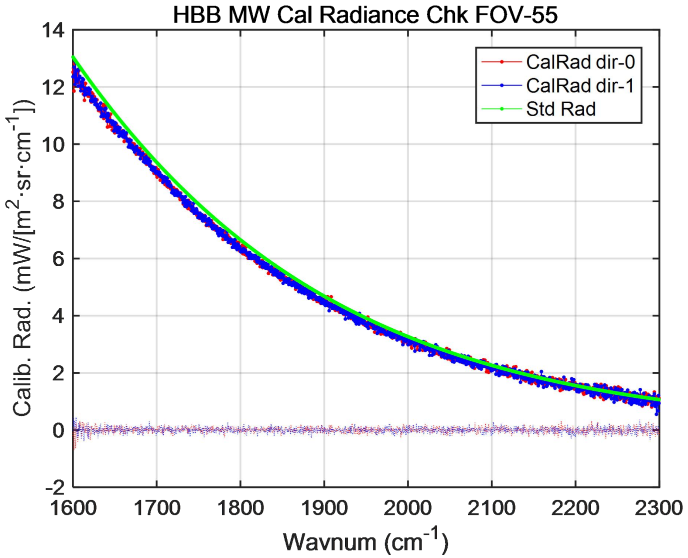
5. FY-4/GIIRS Radiometric Calibration







LWIR



MWIR

- One Case:
  - CBB-Temp：76.437K
  - VBB-Temp：280.151K
  - ICT-Temp：300.196K

Radiometric Calibration Model:

$$L_{\mathrm{VBB}}(\sigma)=\left[\frac{C_{\mathrm{VBB}}(\sigma)-\langle C_{\mathrm{CBB}}(\sigma)\rangle}{\langle C_{\mathrm{ICT}}(\sigma)\rangle-\langle C_{\mathrm{CBB}}(\sigma)\rangle}\right]\cdot L_{\mathrm{ICT}}(T_{\mathrm{ICT}},\sigma)+\left[\frac{\langle C_{\mathrm{ICT}}(\sigma)\rangle-C_{\mathrm{VBB}}(\sigma)}{\langle C_{\mathrm{ICT}}(\sigma)\rangle-\langle C_{\mathrm{CBB}}(\sigma)\rangle}\right]\cdot L_{\mathrm{CBB}}(\sigma)$$

$$=\left[\frac{C_{\mathrm{VBB}}(\sigma)-\langle C_{\mathrm{CBB}}(\sigma)\rangle}{\langle C_{\mathrm{ICT}}(\sigma)\rangle-\langle C_{\mathrm{CBB}}(\sigma)\rangle}\right]\cdot\left[L_{\mathrm{ICT}}(T_{\mathrm{ICT}},\sigma)-L_{\mathrm{CBB}}(\sigma)\right]+L_{\mathrm{CBB}}(\sigma)$$

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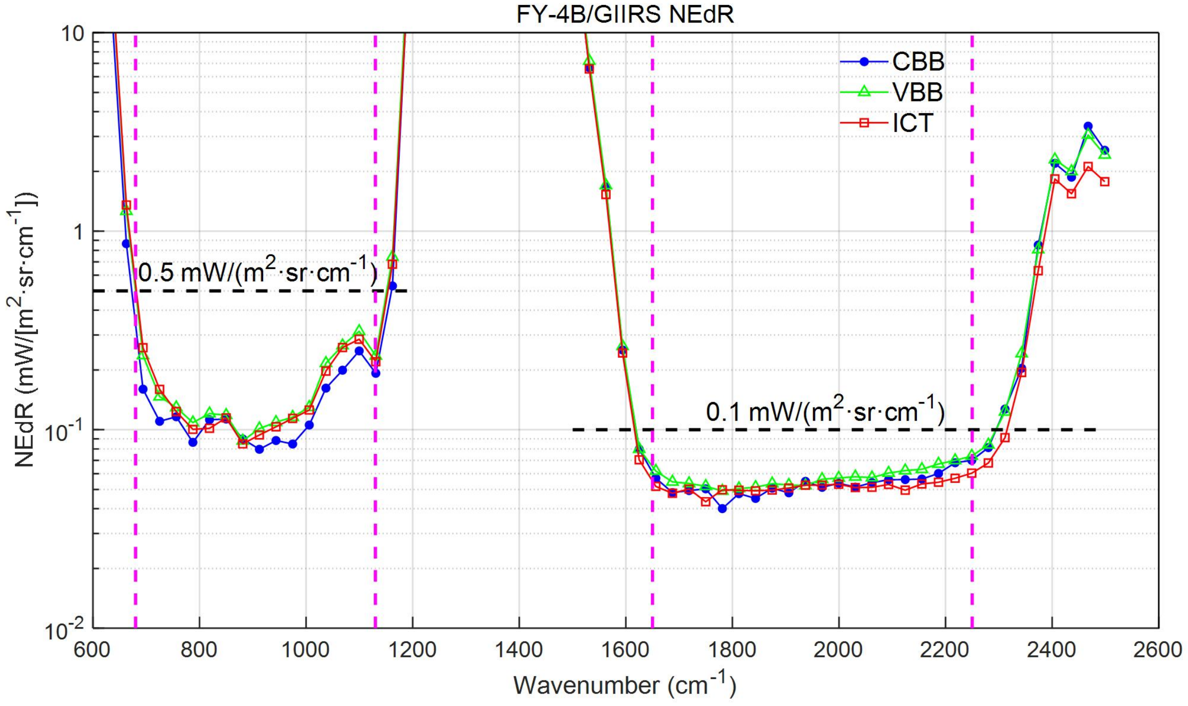
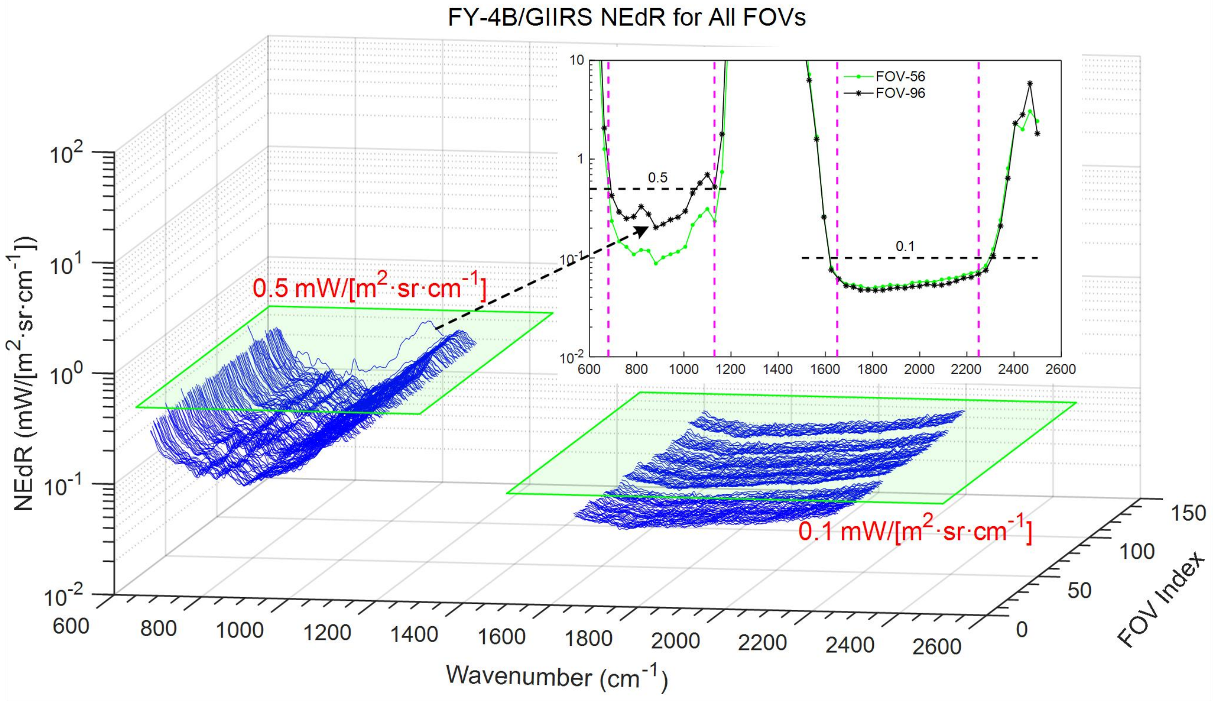
5. FY-4/GIIRS Radiometric Calibration



NEdR estimated from calibrated spectra of CBB, VBB, and ICT, respectively. The dash lines define the spectral ranges of two bands with LWIR: 680~1130 cm^{-1}, and MWIR: 1650~2250 cm^{-1}.



GIIRS NEdR of all pixels in two bands.

- ➢ GIIRS NEdR meets the requirement of 0.5 r.u. in LWIR band and 0.1 r.u. in MWIR band.
- ➢ Due to defects in the detector process, the NEdR of Pixel-16,-17,-31,-96 is larger than others, especially Pixel-96.

$$NEdR(\sigma)=\sqrt{\frac{1}{M-1}\sum_{j=1}^{M}\left[\mathrm{Re}\{L_j(\sigma)\}-\langle\mathrm{Re}\{L_j(\sigma)\}\rangle\right]^2}$$

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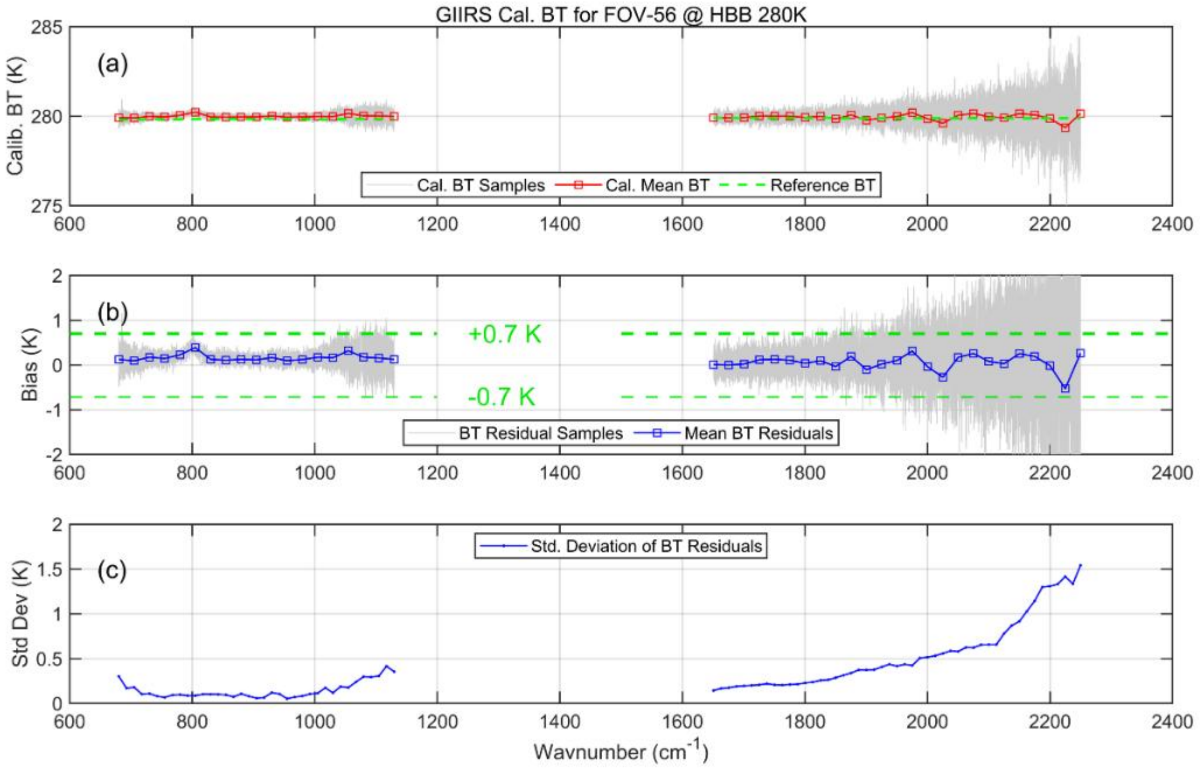
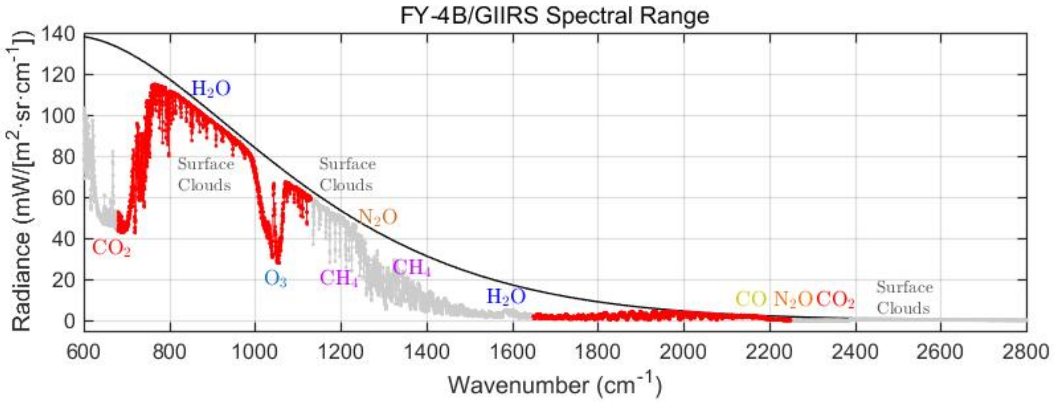
5. FY-4/GIIRS Radiometric Calibration

Radiometric calibration error of Pixel-56 for a 280K reference source



GIIRS Radiometric calibration results. (a) bright temperatures (BT) of FOV-56, (b) brightness temperature differences with an averaged bias and (c) standard deviation of the BT differences.



- In general, according to TVAC test, the average deviation of GIIRS radiometric calibration meets the requirement of 0.7 K, but the noise or low SNR still affects the radiometric accuracy in the LWIR edge channels and in the MWIR 2000~2250cm^{-1} spectral range. Considering the large water vapor absorption lines in the MWIR band, the detection of 4.4~6.06 µm infrared radiation in geostationary orbit is indeed a great challenge.

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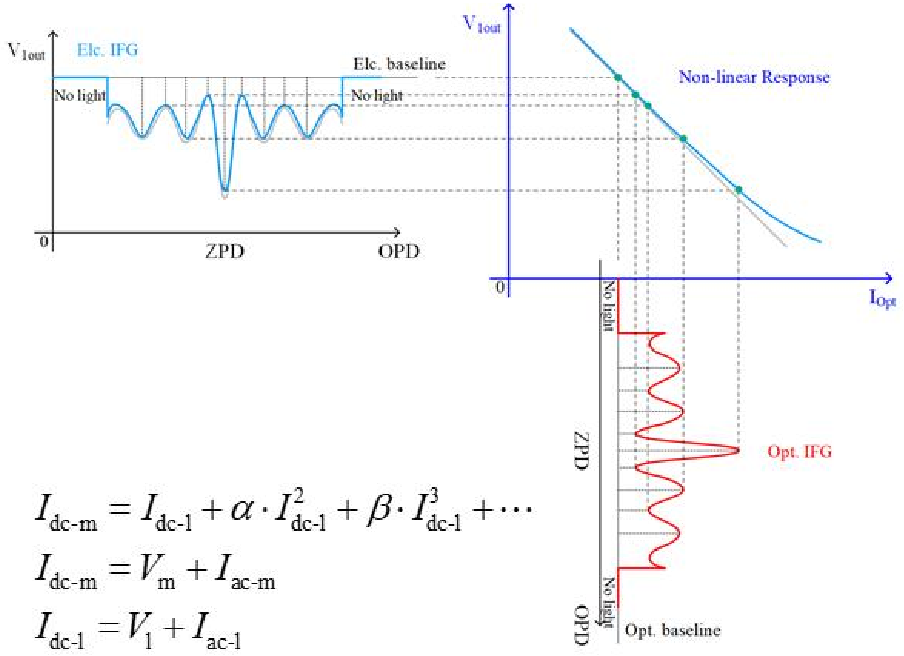
5. FY-4/GIIRS Radiometric Calibration

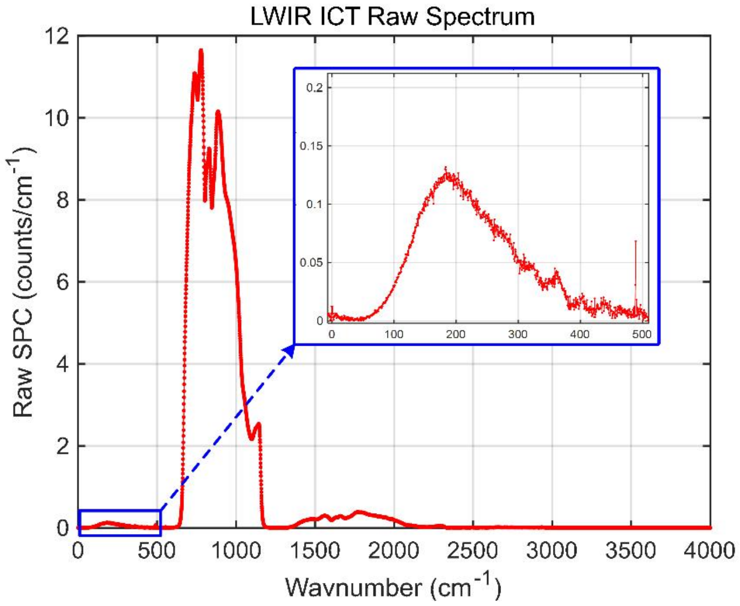
Nonlinear response of LWIR photoconductive infrared detector



$$I_{\text{dc-m}} = I_{\text{dc-1}} + \alpha \cdot I_{\text{dc-1}}^2 + \beta \cdot I_{\text{dc-1}}^3 + \cdots$$

$$I_{\text{dc-m}} = V_{\text{m}} + I_{\text{ac-m}}$$

$$I_{\text{dc-1}} = V_1 + I_{\text{ac-1}}$$



Pseudo-spectral features caused by nonlinear effect with that in low wavenumber range shown in zoom-in subplot

- GIIRS LWIR uses a photoconductive HgCdTe detector, which has a high nonlinear response, while MWIR uses a photovoltaic HgCdTe detector, which has a good linear response.
- The linear calibration principle requires that the instrument should be a linear response system. Therefore, a non linearity correction step is performed on the interferograms or on the raw spectra.

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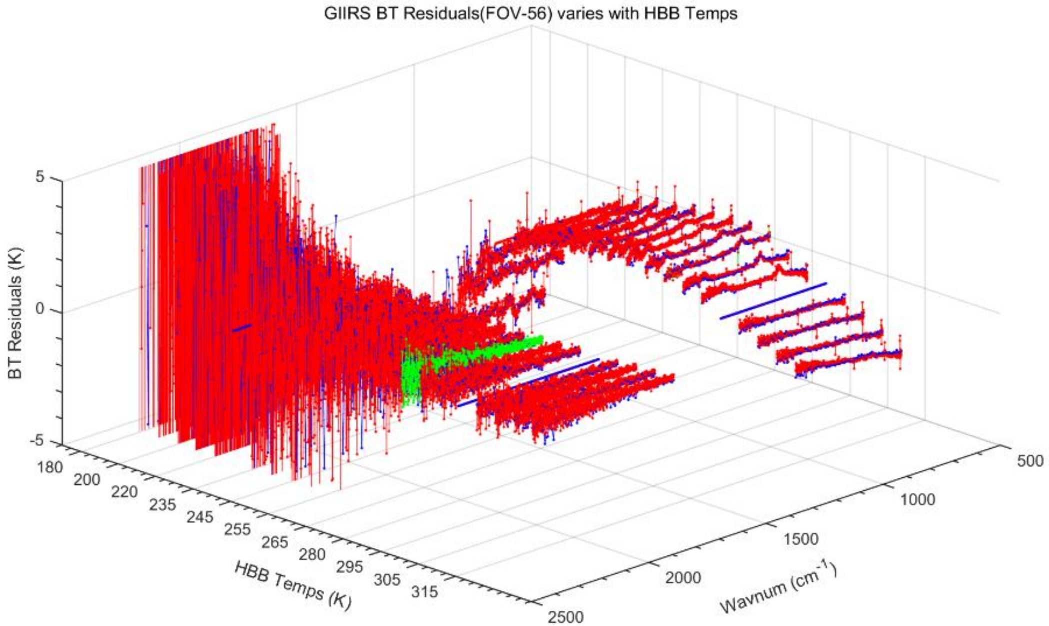
5. FY-4/GIIRS Radiometric Calibration



- Due to the nonlinear effect, the radiometric calibration deviation of LWIR band will change with the VBB temperature. For the MWIR band, the radiometric calibration deviation does not change with VBB temperature, but it is greatly affected by noise when observing cold scenes.

LWIR Nonlinearity Correction Method

$$IFG_{NLC} = IFG_m + a_2 \cdot IFG_m^2 + \cdots$$

$$IFG_m = V_m + IGM_m$$

$$C_{NLC}(\sigma) = (1 + 2a_2 \cdot V_m) \cdot C_m(\sigma)$$

$$V_m(\sigma) = \frac{1}{\rho} \sum \left| C_m(\sigma) \right|$$

$$InsResp(\sigma) = \frac{\left| C_{VBB}(\sigma) - C_{CBB}(\sigma) \right|}{L_{VBB}(\sigma, T_{VBB})}$$

$$a_2 = \arg\min_{a_2} \left\{ \frac{1}{n-1} \sum_{j=1}^{n} \left[InsResp_j(\sigma) - \langle InsResp_j(\sigma) \rangle \right]^2 \right\}$$

IFG_m: measured interferogram with AC item IGM_m and DC V_m.
IFG_{NLC}: nonlinearity corrected interferogram.
C_m: nonlinear spectrum, FFT$\{IGM_m\}$.
C_{NLC}: nonlinearity corrected spectrum.
ρ: modulation depth of interferogram.
$InsResp$: instrument responsivity varying with wavenumber σ.
L_{VBB}: radiance of VBB at temperature of T_{VBB}.
$<\cdot>$: sample average operator.

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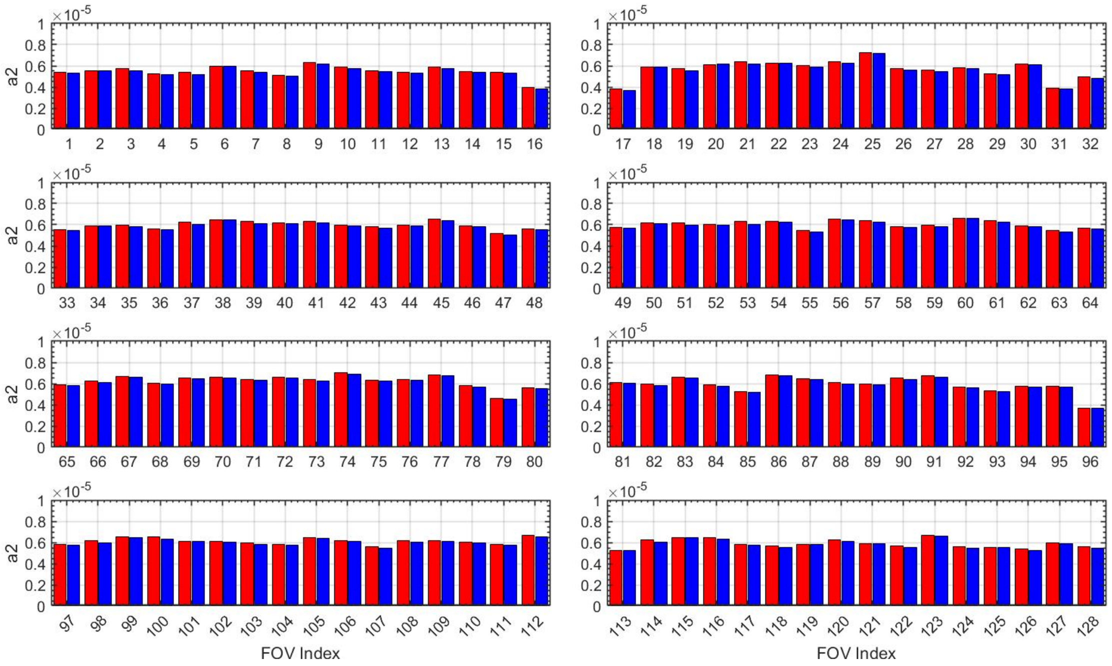
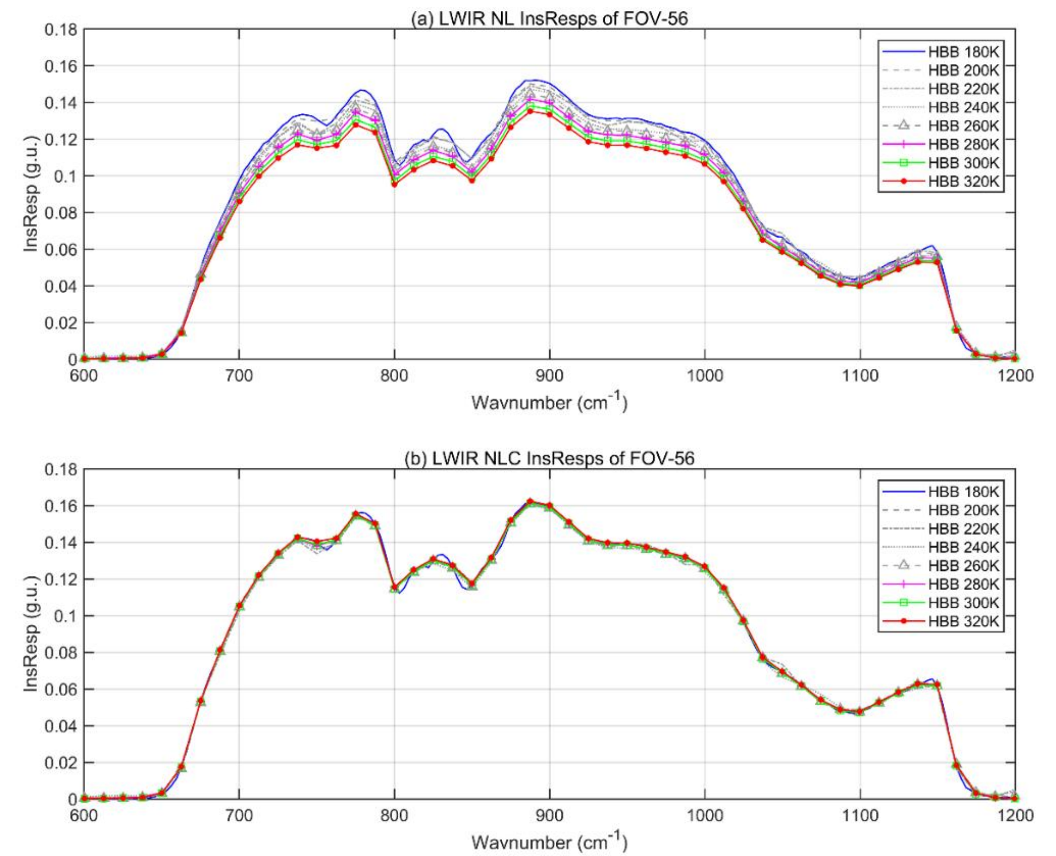
5. FY-4/GIIRS Radiometric Calibration



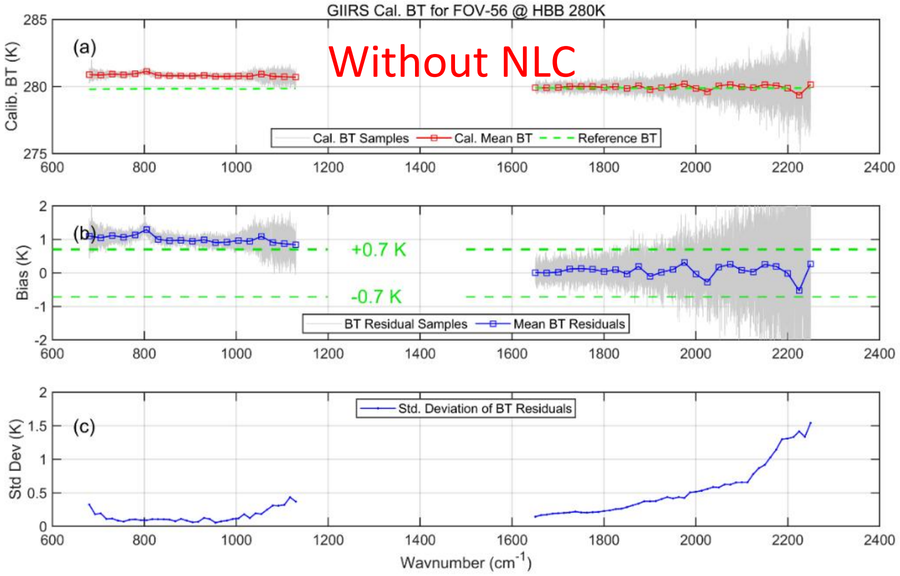
LWIR nonlinearity correction coefficients (a_2) for all 128 pixels.

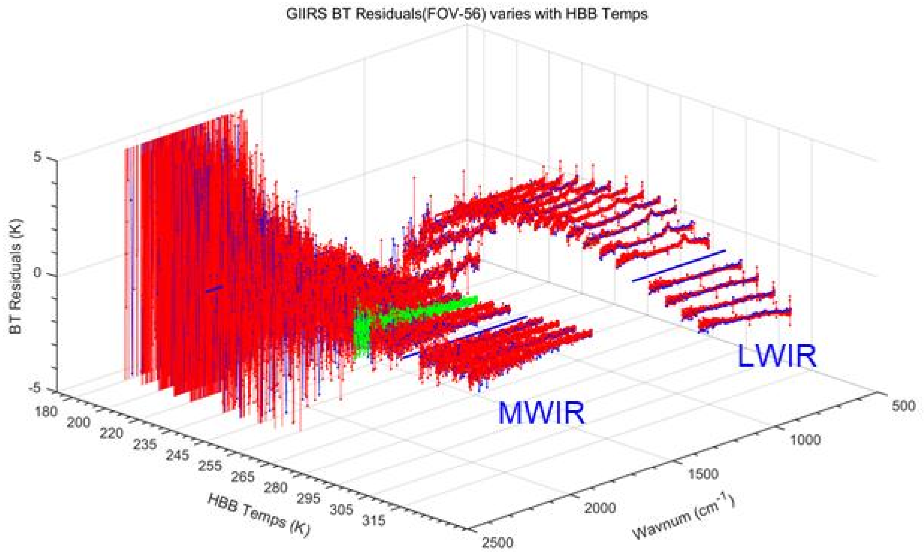


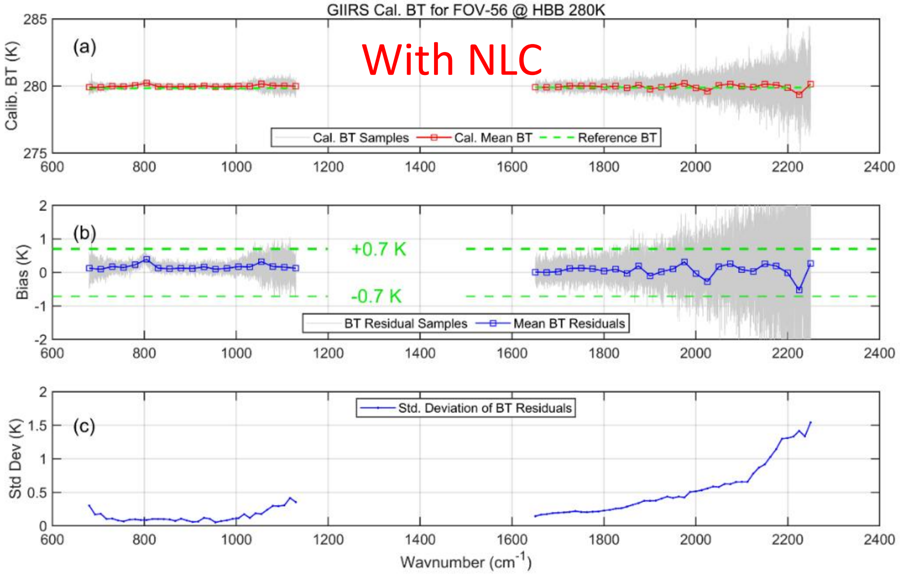
(a) FOV-56 responsivities for different HBB temperature before the nonlinearity correction; (b) FOV-56 responsivities after the nonlinearity correction.

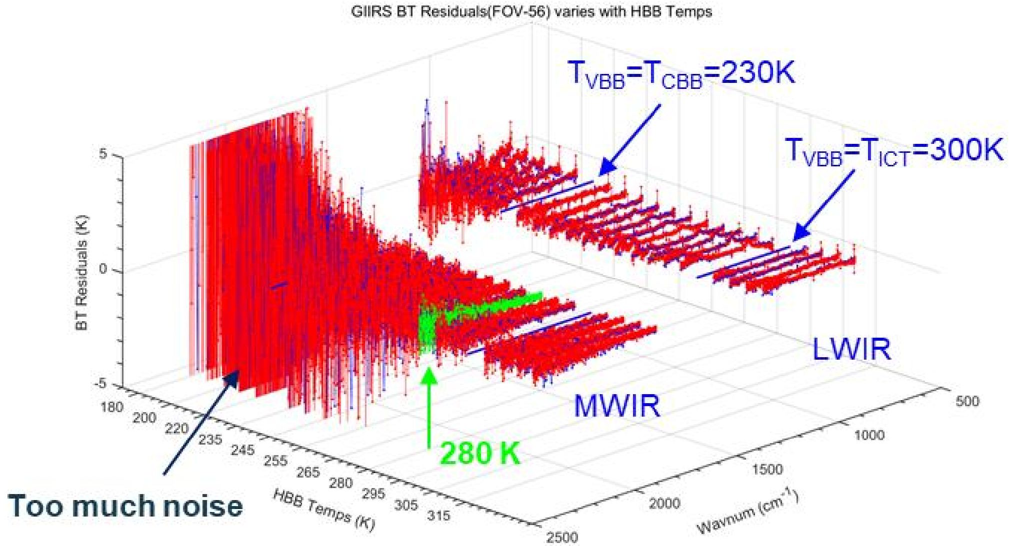
- The NLC method is based on the fact that the instrument responsivity for a linear response system should remain constant even if the temperature of observed scene varies.
- as long as we find a suitable nonlinear correction coefficient that converges the instrument responsivities at different VBB temperatures, then a nonlinear spectrum is corrected to a linear spectrum.

5. FY-4/GIIRS Radiometric Calibration



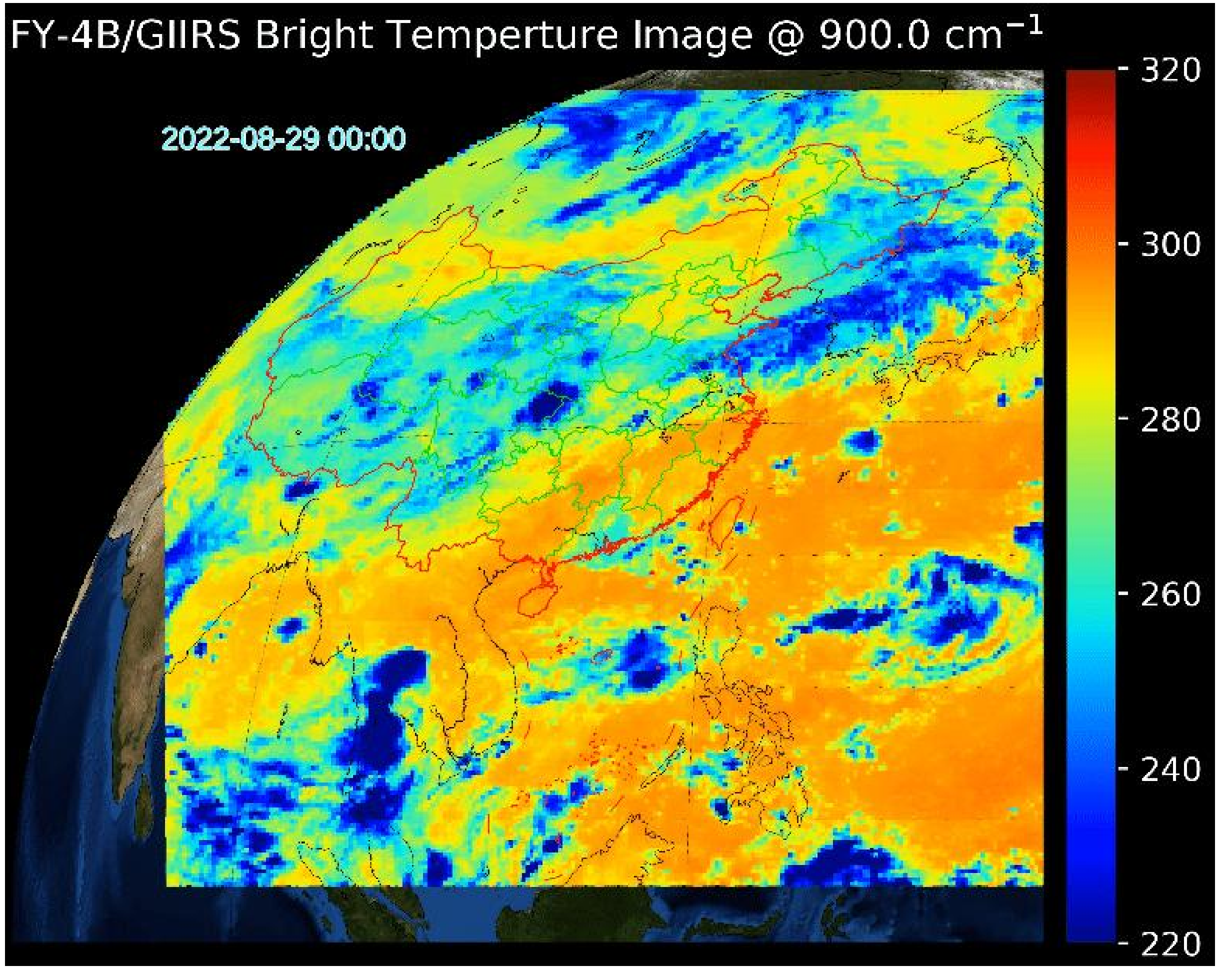


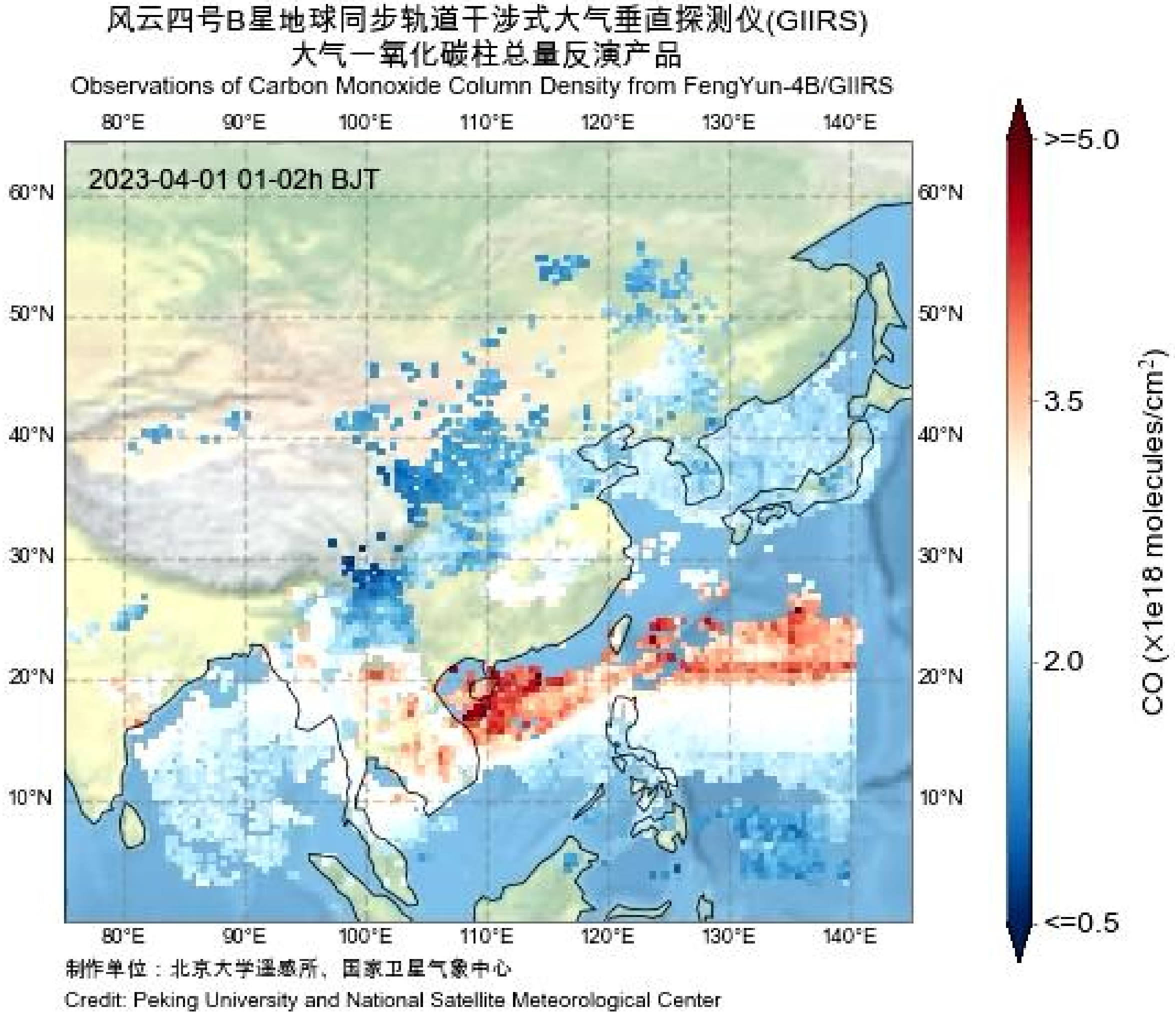




- After nonlinear correction, the radiometric calibration deviations of the LWIR detector for VBB observations are all within the 0.7 K requirements.
- The MWIR detector has a good linear response, while it is affected too much by noise when observing cold scenes.

6. Post-launch Applications





- Typhoon Hinnamnor observation by FY-4B/GIIRS.
- Transportation of CO Column Density from FY-4B/GIIRS Observations.

That's all Folks
Thank you for your attention

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