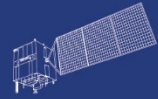


HY



HJ-1AB



CBERS



Gaofen



Beijing-2



Sentinel-1



Sentinel-2



Sentinel-3



Sentinel-5p



Aeolus

ON-ORBIT CALIBRATION AND VALIDATION OF THE GREENHOUSE GASES MONITORING INSTRUMENT (GMI) ON GF5-02 SATELLITE

Hailiang SHI

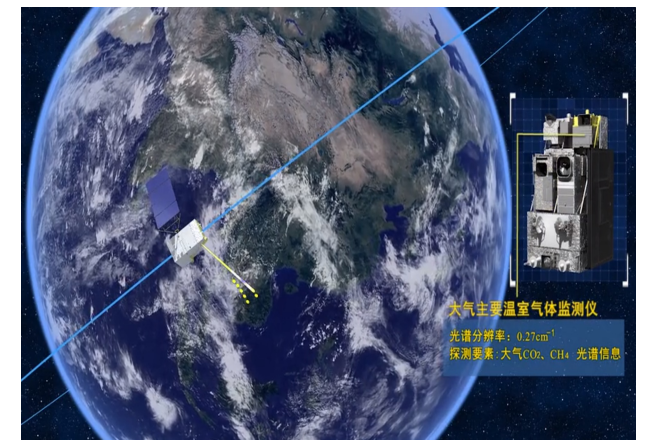
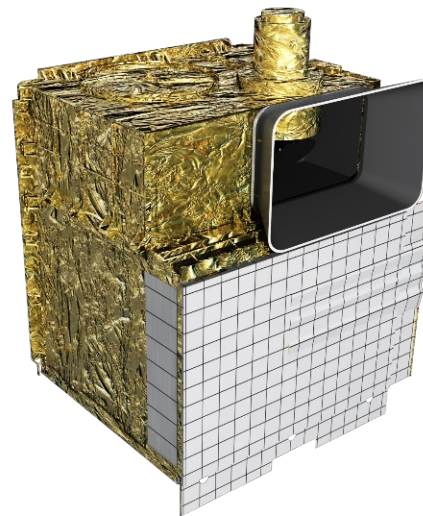
13 SEPTEMBER 2023

PROJECT ID. 58873

Hefei Institute of Physical Science, Chinese Academy of Sciences

- Objective
- Overview of the GMI
- Level 1 Processing Algorithm
- Geometric Correction Algorithms
- Level 1 Product Results
- Retrieval Results
- Plans

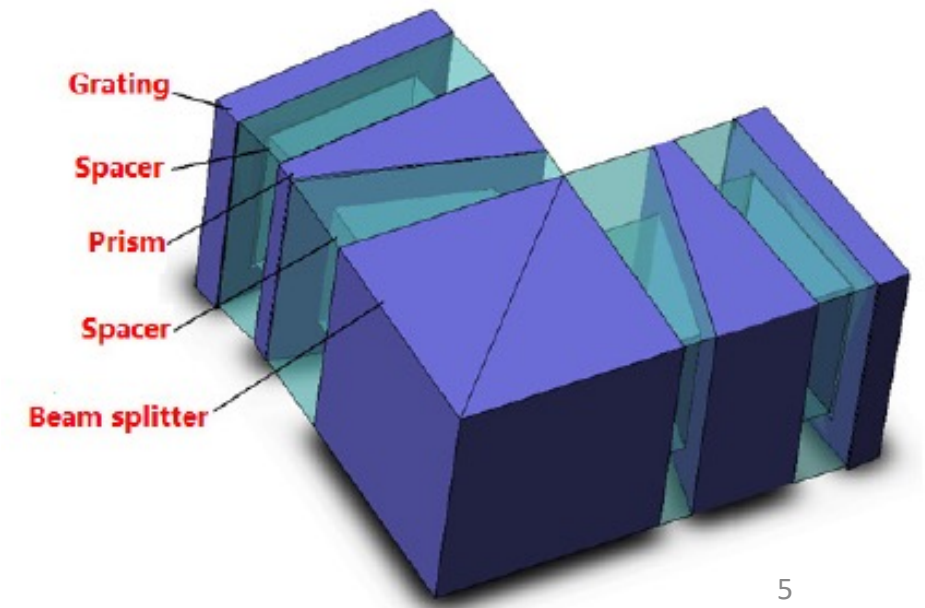
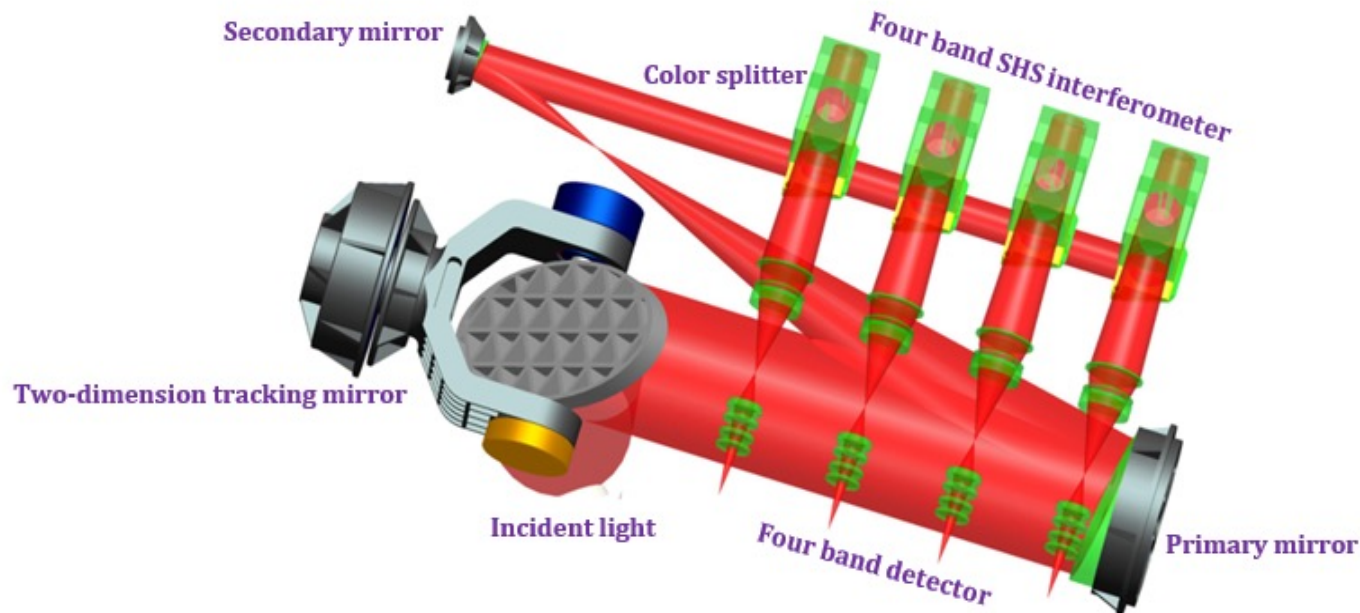
- THE GF5-02(GAOFEN5-02) satellite is the latest satellite to achieve hyperspectral resolution observations in the CHEOS (China High-Resolution Earth Observation System.)
- It was successfully launched from the Taiyuan Satellite Launch Center in 2021
- GMI is mainly used to obtain global column concentration data on the GHGs carbon dioxide (CO₂) and methane (CH₄)



- The GMI payload on the GF5-02 satellite adopts a novel form of spectroscopy, namely, SHS, to obtain the atmospheric absorption spectrum.
- The mechanism of the GMI is different from TANSO-Fourier transform spectroscopy (FTS)/GOSAT (Michelson interferometer) and OCO-2 (Grating), the data processing algorithms are quite different.
- The main objective is to introduce the processing algorithm for the Level 1 product (radiance spectrum) developed for the GMI and to discuss the first results of the hyperspectral-resolution spectrum from the GMI.

Instrument

- Compared with a conventional Michelson interferometer, the SHS interferometer replaces the moving mirrors with diffraction gratings, resulting in extremely high spectral resolution within a narrow band.



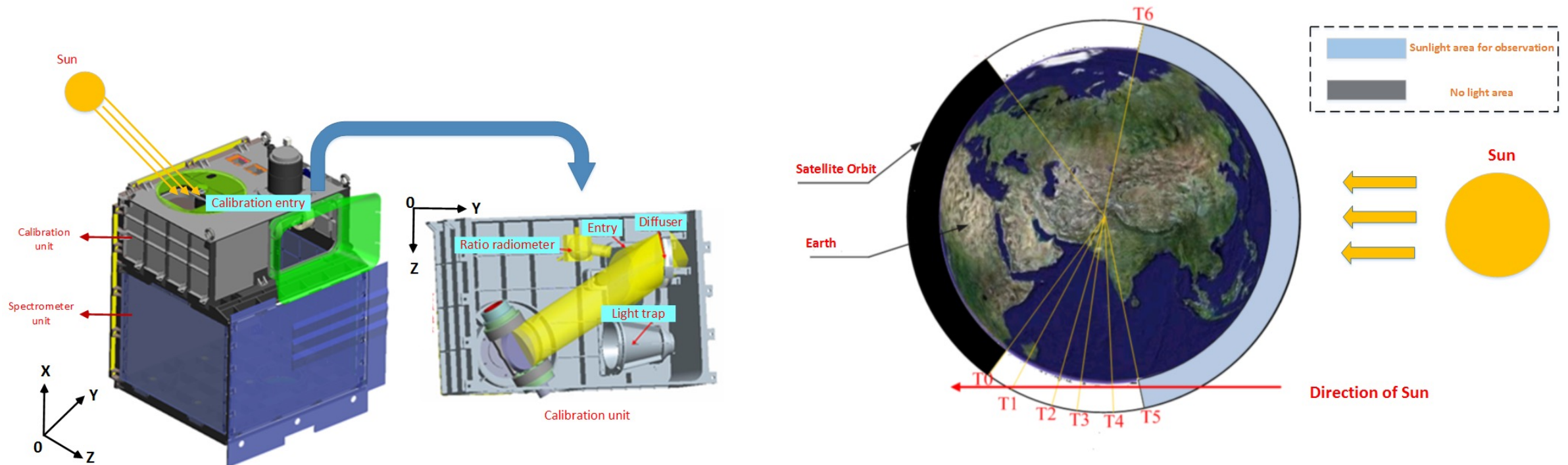
Instrument

Specifications of the GMI

Specifications	Values			
	Band 1	Band 2	Band 3	Band 4
Detected gas	O ₂	CO ₂	CH ₄	CO ₂
Band range (μm)	0.759-0.769	1.568-1.583	1.642-1.658	2.043-2.058
Spectral resolution (cm ⁻¹)	0.6	0.27		
SNR (albedo=0.3; sun elevation=30°)	300		250	
Radiometric calibration	absolute accuracy: 5%, relative accuracy: 2%			
FOV	14.6 mrad (10.3 km @ 705 km)			
Scan	Cross track (±35°), Along track (±20°)			
Observation modes	Nadir: 1, 5, 7, 9 points (default mode is 5 points); Sun glint; Calibration			
Number of detector pixels	1024×1024	512×640	512×640	256×320

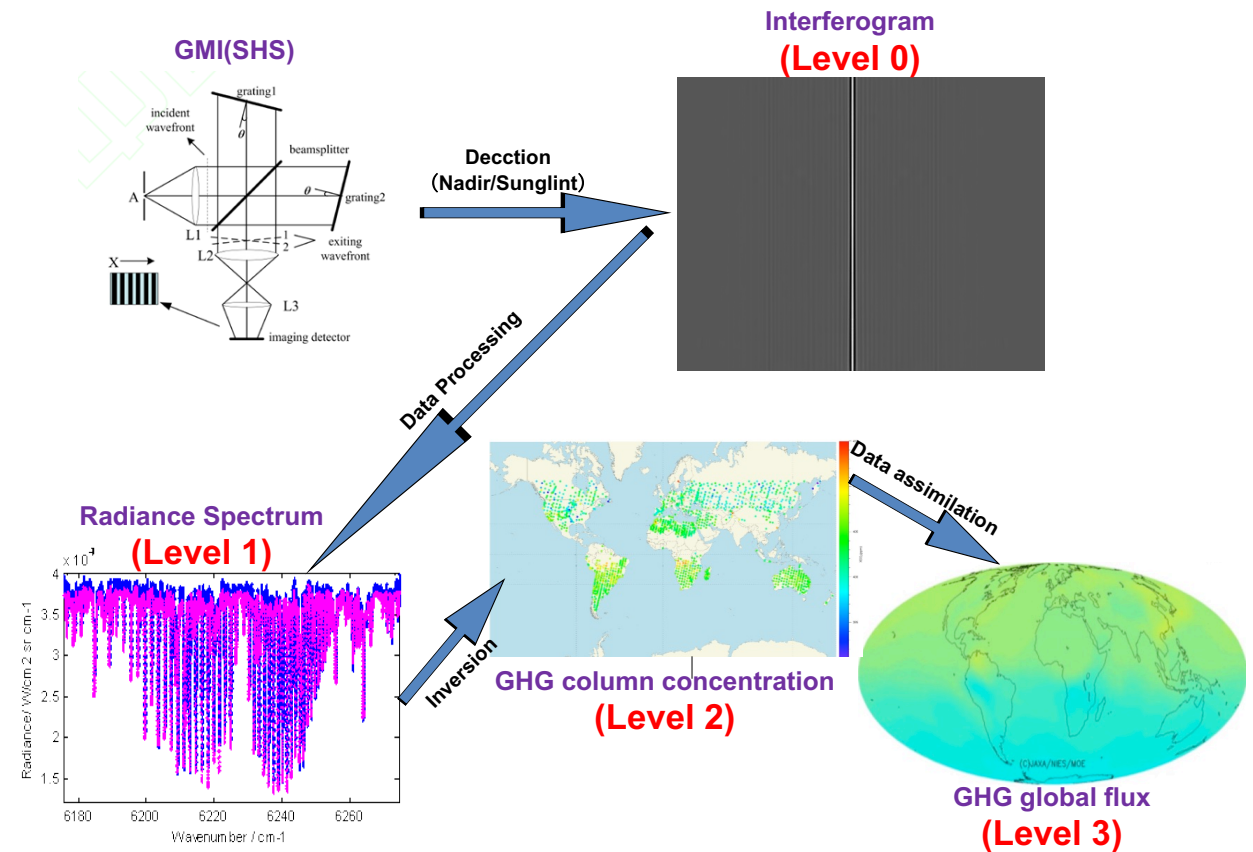
Instrument

To improve the data accuracy, the GMI is going to carry out a calibration, the 2-D tracking mirror is adjusted from the nadir/sun-glint observation mode to the calibration mode

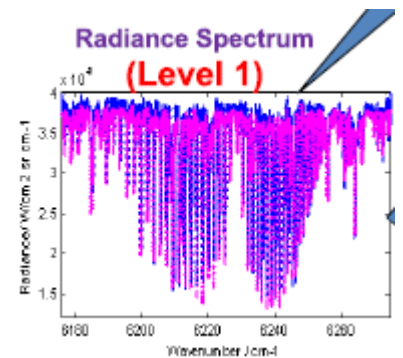
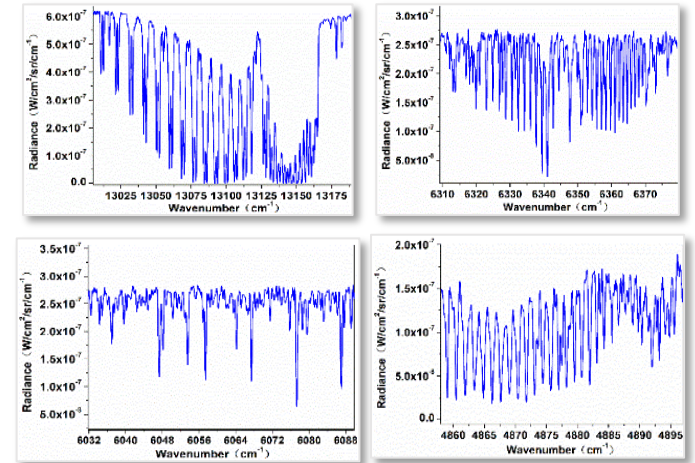
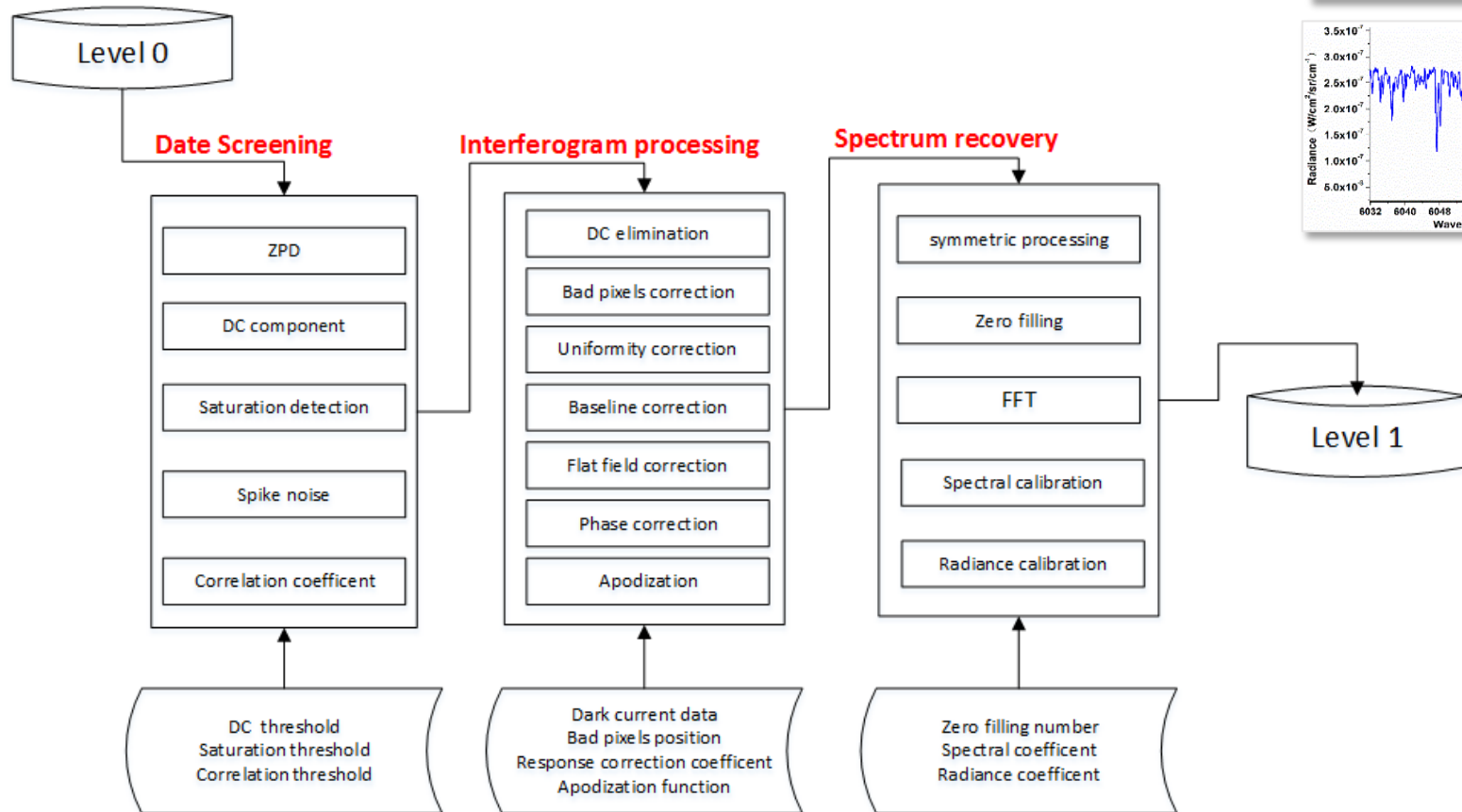
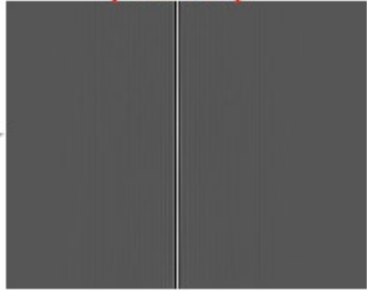


Products

- Level 0: The original data obtained by the GMI are in the form of an interferogram
- Level 1: The radiance spectrum obtained through the processing of error correction, Fourier transform, spectral calibration, and radiation calibration of the satellite downloaded detection data
- Level 2: global column concentration distribution data of CO₂ and CH₄
- Level 3: the global carbon flux and 3-D distribution of CO₂ and CH₄



Interferogram
(Level 0)



Data Screening

ZPD Deviation

ZPD position different from the normal value

Low SNR

Low SNR which is sampled above surface with low reflectivity

Saturation Detection

Saturated by an area with high reflectivity or cloud coverage

Spike Noise

With spike noise influenced by the space environment

Correlation Coefficients

Without effective modulation information

Interferogram Processing

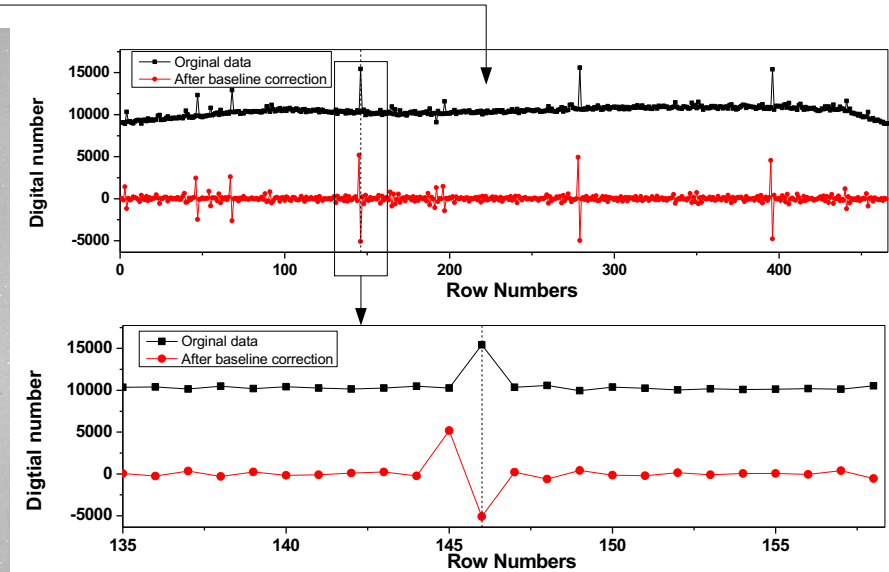
Bad Pixel Correction

Baseline Elimination

Flat-Field Correction

Phase Correction

Apodization



Interferogram Processing

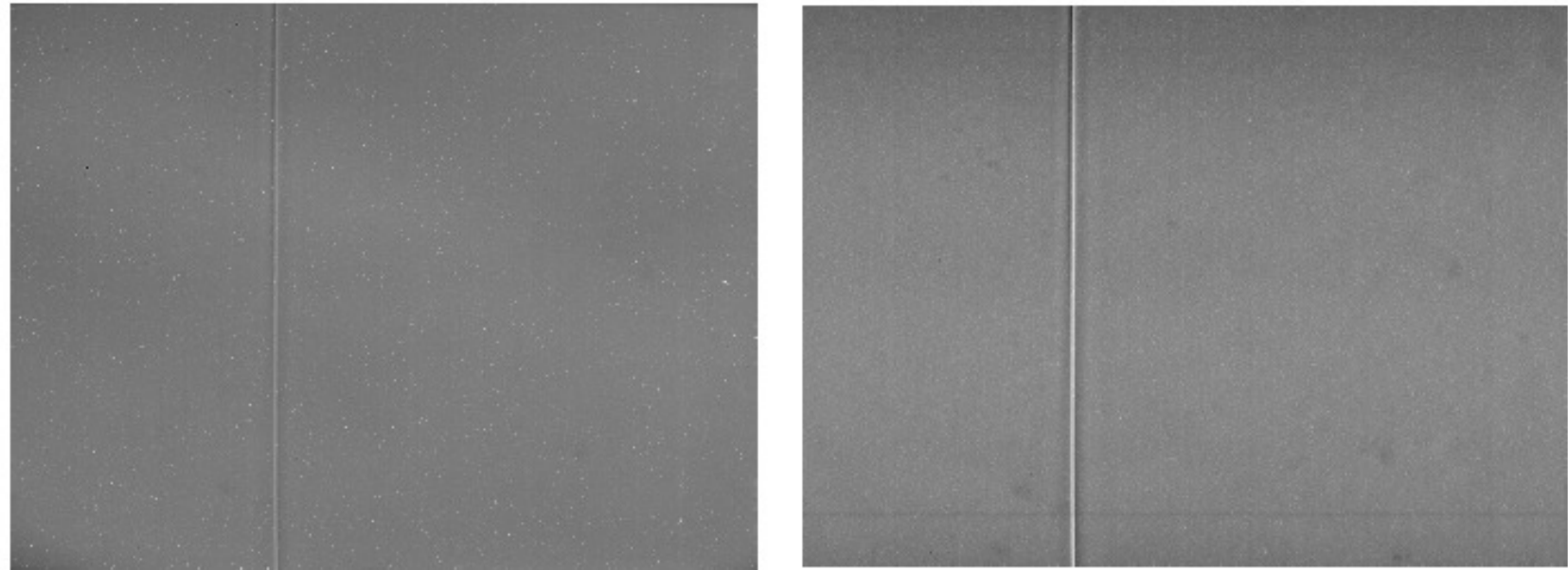
Bad Pixel Correction

Baseline Elimination

Flat-Field Correction

Phase Correction

Apodization



Bad pixel correction result (GMI Band 2 interferogram). (Left) Before correction. (Right) After correction.

Interferogram Processing

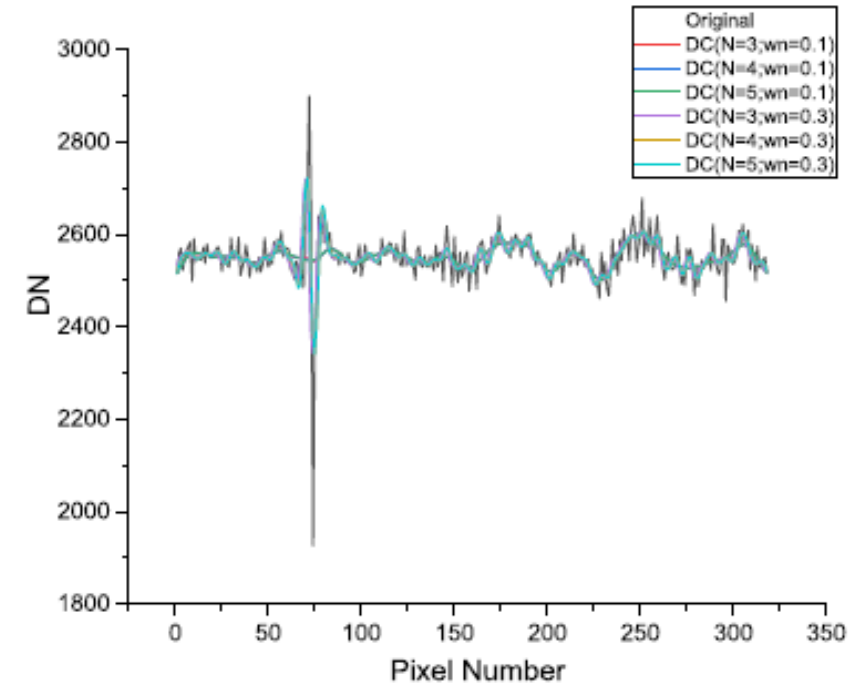
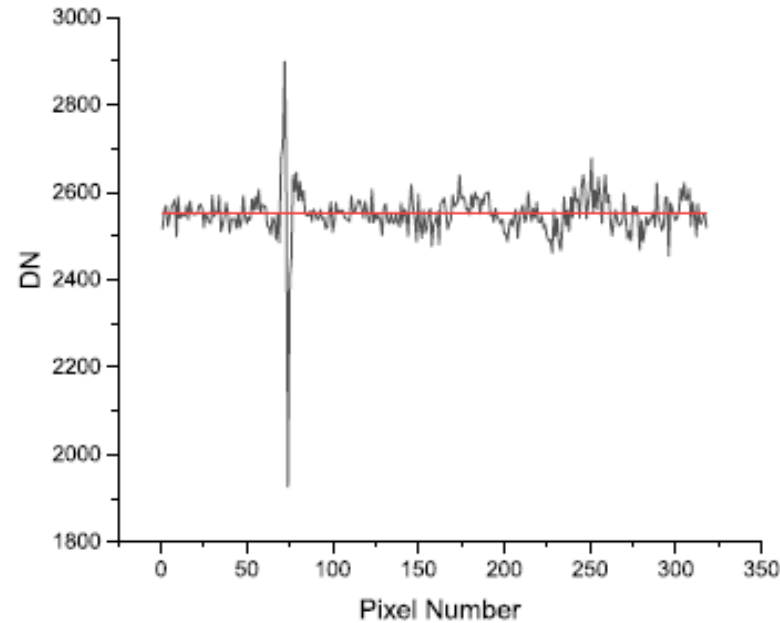
Bad Pixel Correction

Baseline Elimination

Flat-Field Correction

Phase Correction

Apodization



Baseline elimination results (GMI Band 3 interference fringe). (Left) Polynomial fitting method. (Right) Butterworth low-pass filter method.

Interferogram Processing

Bad Pixel Correction

Baseline Elimination

Flat-Field Correction

Phase Correction

Apodization

- The SHS interferometer adopts the area array detector to collect the interference fringes simultaneously. This method has better stability, but at the same time, it also introduces a nonuniform response factor that the Michelson interferometer does not have.
- The traditional flat-field method is not applicable, To solve the problem of SHS flat-field correction, the balanced arm flat-field method has been used.

Interferogram Processing

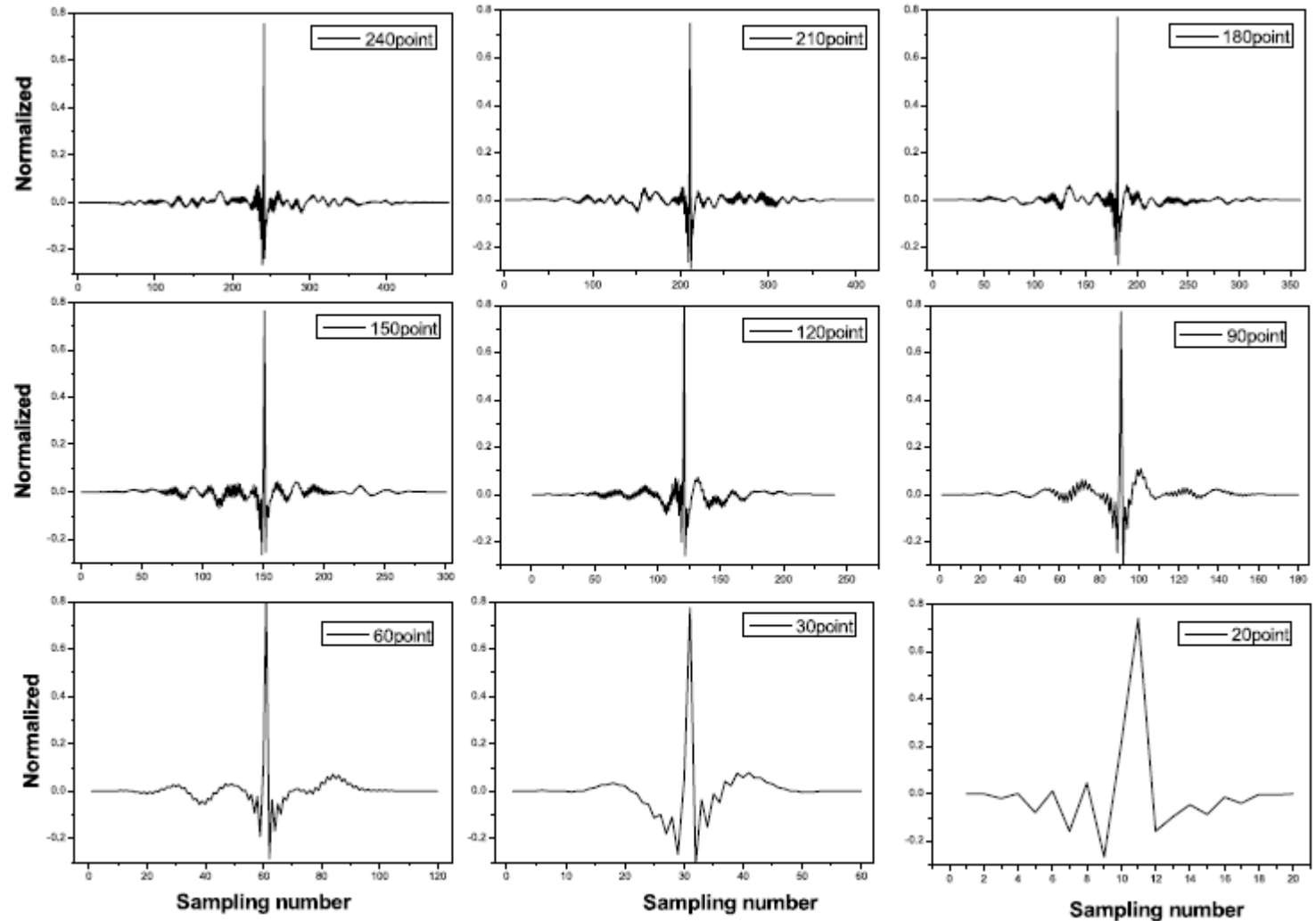
Bad Pixel Correction

Baseline Elimination

Flat-Field Correction

Phase Correction

Apodization



Interferogram Processing

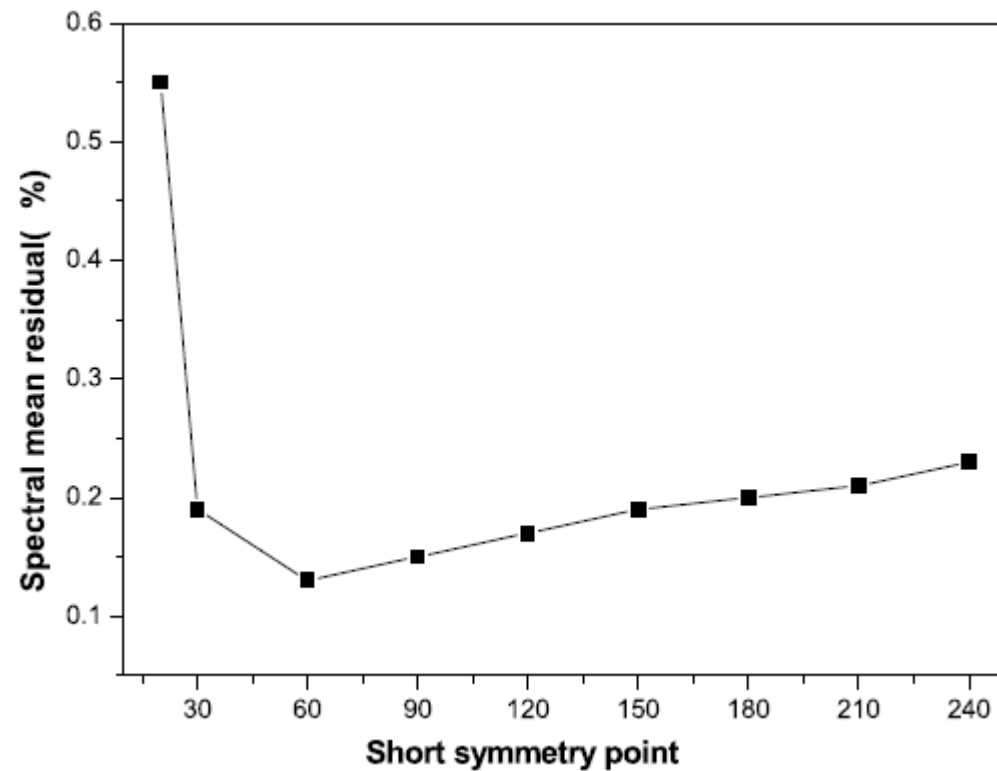
Bad Pixel Correction

Baseline Elimination

Flat-Field Correction

Phase Correction

Apodization



Interferogram Processing

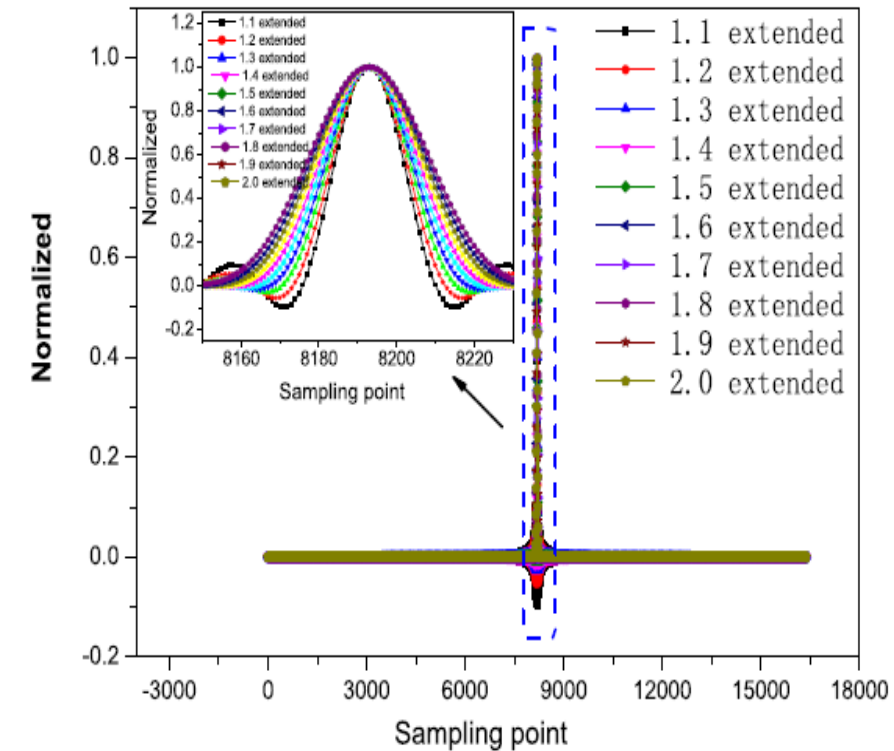
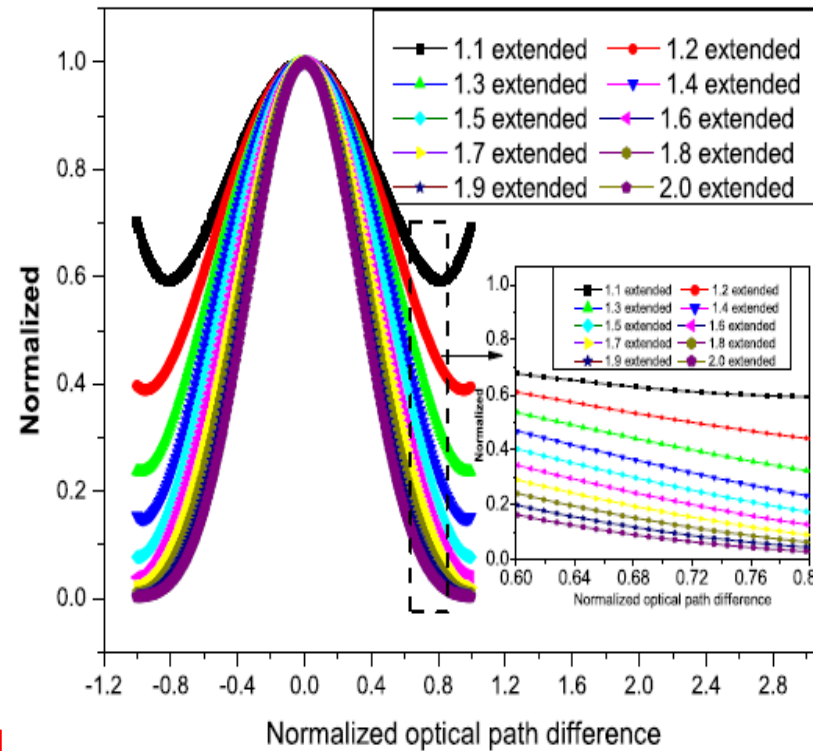
Bad Pixel Correction

Baseline Elimination

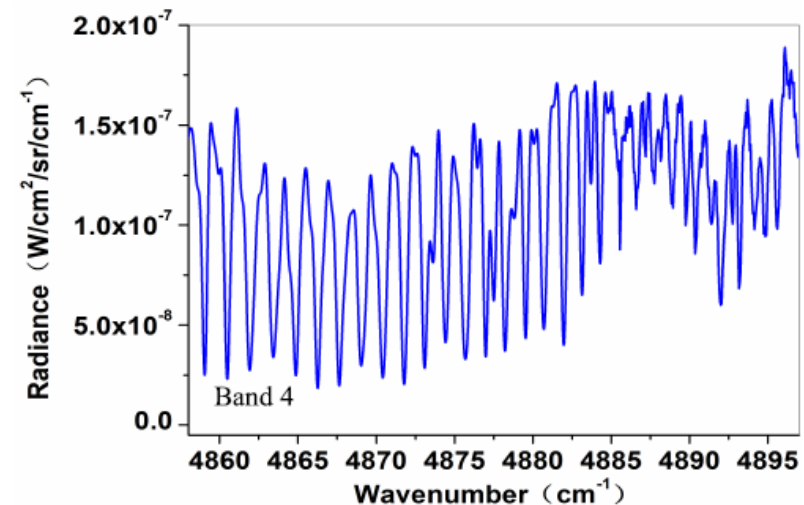
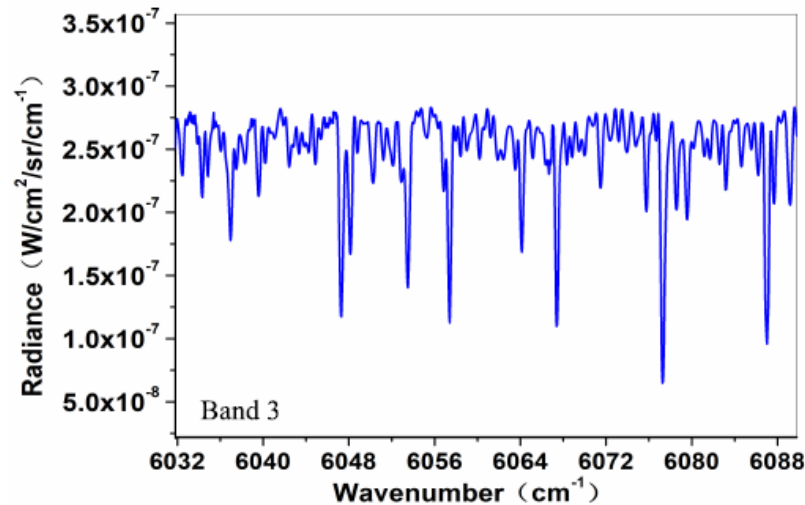
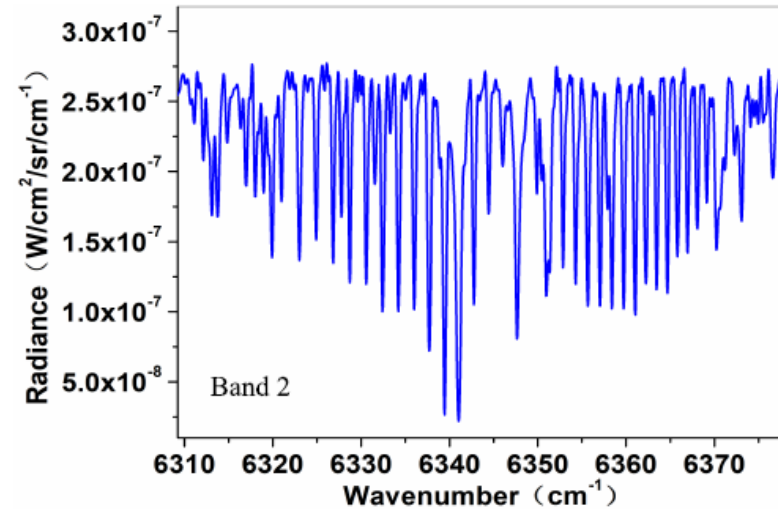
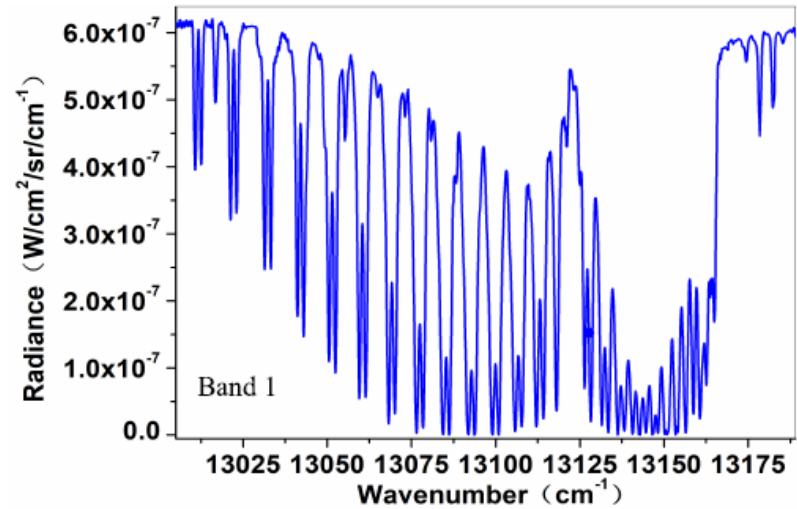
Flat-Field Correction

Phase Correction

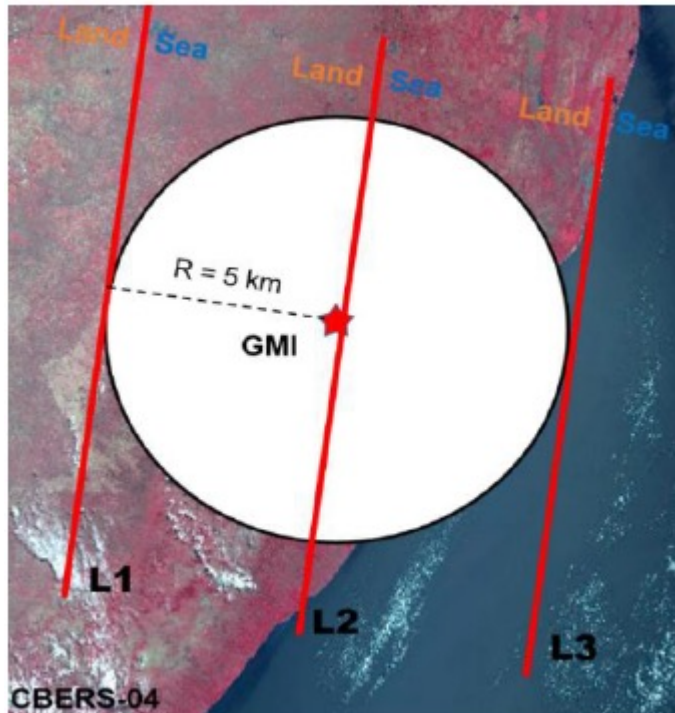
Apodization



Spectrum Recovery



Method



- L1: the observation point is tangent to the coastline and is located on the land, which reflectivity is high
- L2 (the observation point is tangent to the coastline)
- L3: the observation point is tangent to the coastline and is located in the ocean, which reflectivity is weak

Land interferogram is I_L and the ocean interferogram is I_S , the coastline interferogram is I_C . Parameters a and b are the proportions of land and ocean.

$$I_C = a \cdot I_L + b \cdot I_S$$

$$a + b = 1.$$

or

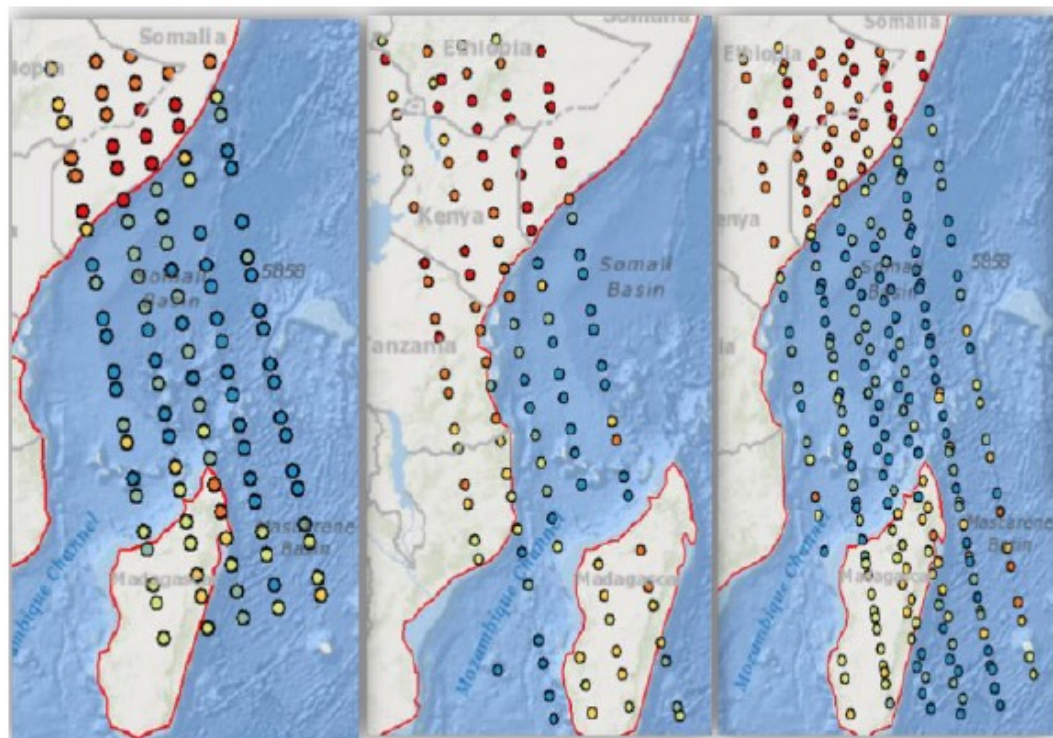
$$I_{j-1} \leq I_j \leq I_{j+1}, \quad I_j \in [T_1, T_2]$$

$$I_{j-1} \geq I_j \geq I_{j+1}, \quad I_j \in [T_1, T_2]$$

T_1 and T_2 are the thresholds of the averaged DN values of ocean and land interferograms

Results

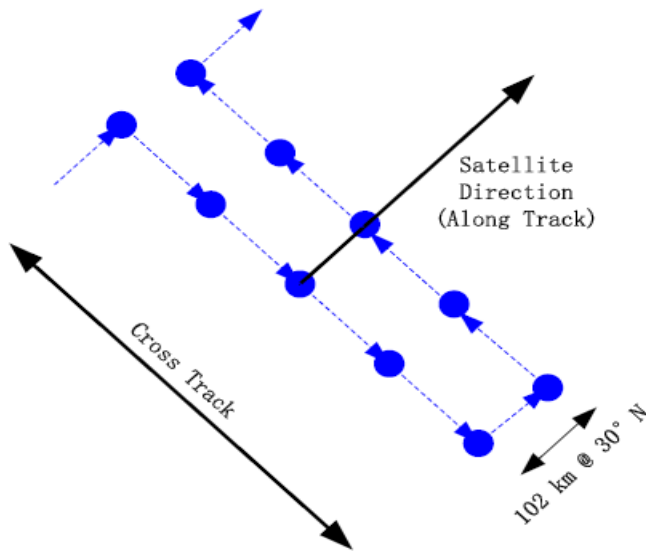
$$\begin{aligned} \text{lon}' &= 1.00154 \cdot \text{lon} + 0.00119 \\ \text{lat}' &= 0.98858 \cdot \text{lat} + 0.01147. \end{aligned}$$



Point	GMI		WFI		Error	
	<i>lon</i>	<i>lat</i>	<i>lon</i>	<i>lat</i>	δlon	δlat
1	-20.710	48.610	-20.709	48.481	-0.001	0.129
2	-0.707	42.315	-0.663	42.277	-0.044	0.038
3	0.611	43.777	0.664	43.595	-0.053	0.182
4	-3.126	40.362	-3.105	40.131	-0.021	0.231
5	-20.749	48.419	-20.735	48.471	-0.014	-0.052
6	-13.723	40.546	-13.716	40.588	-0.007	-0.042
7	-0.205	42.681	-0.207	42.685	0.002	-0.004
8	0.560	43.643	0.657	43.581	-0.097	0.062
9	-2.765	40.145	-2.778	40.224	0.013	-0.079
10	-5.714	38.873	-5.677	38.820	-0.037	0.053
11	-7.262	39.195	-7.218	39.404	-0.044	-0.209
12	-9.934	39.751	-9.874	39.861	-0.060	-0.110

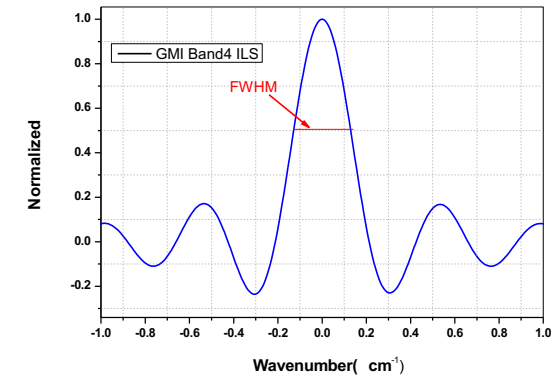
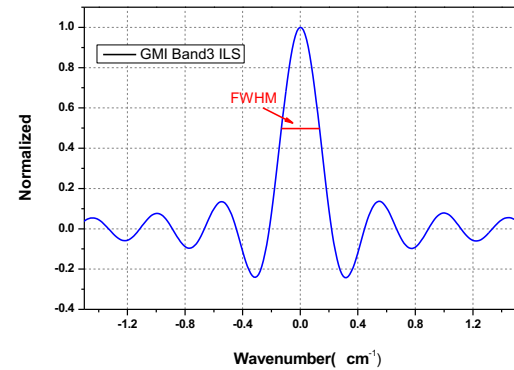
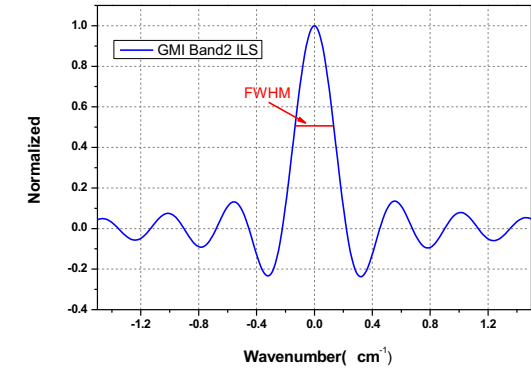
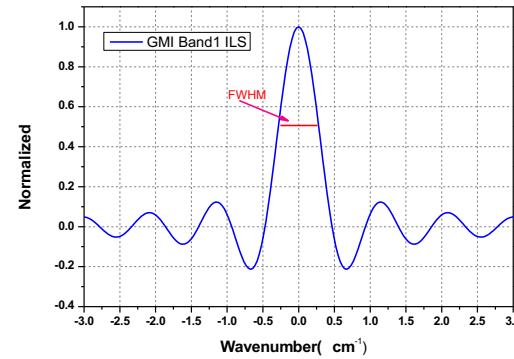
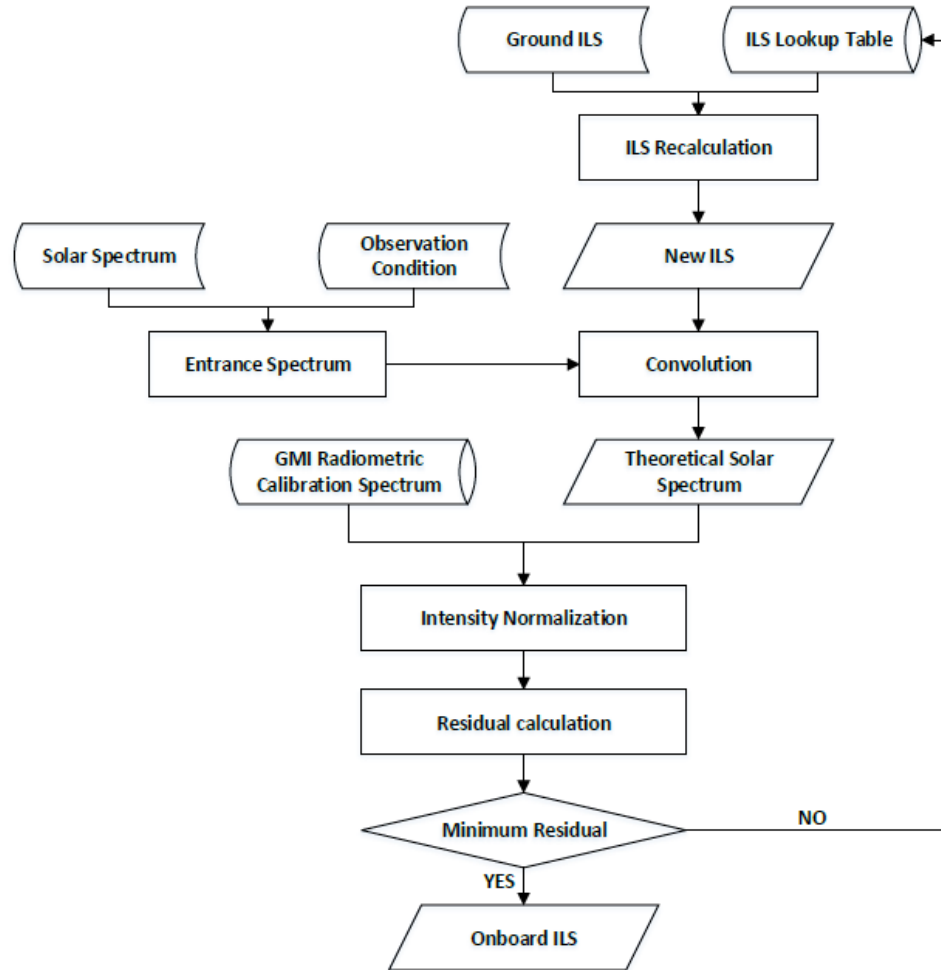
Satellite

- sun-synchronous orbit at an altitude of 705 km with an equatorial crossing local time descending node (LTDN) of 13:30
- completes an orbit in approximately 100 min and operates on a global basis with a 7-day orbit repeat cycle but with a 51-day footprint revisit cycle
- 1–9 cross-track points within $\pm 35^\circ$ of nadir, yielding an ~ 750 -km cross-track range

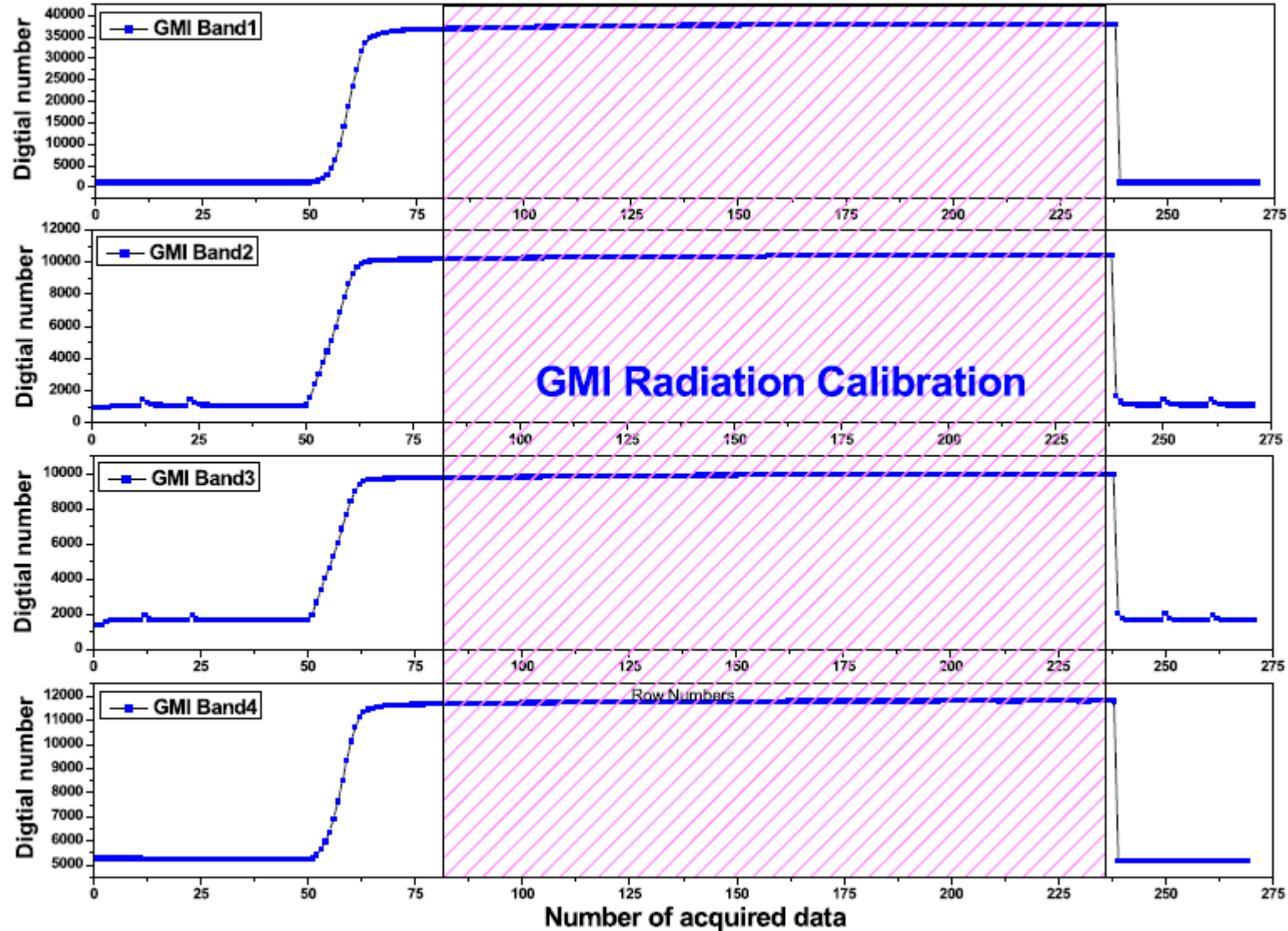


GMI grid point observations in the five-point cross-track scan mode

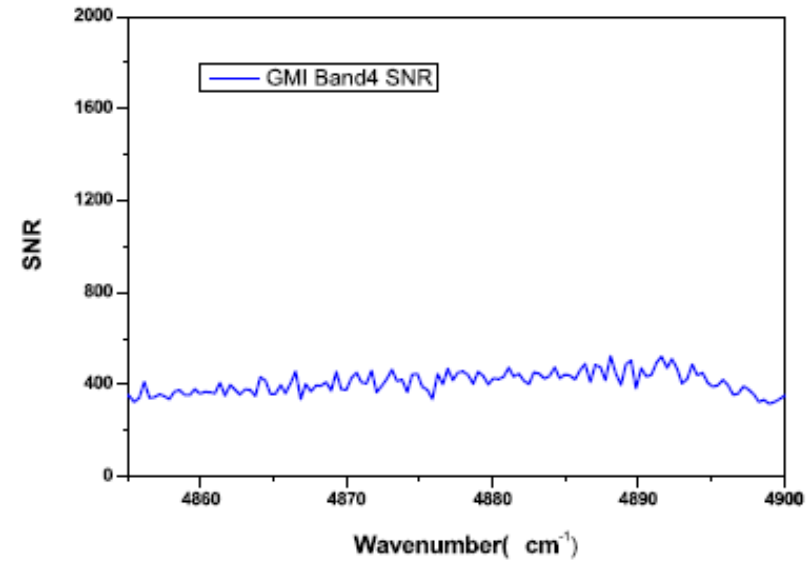
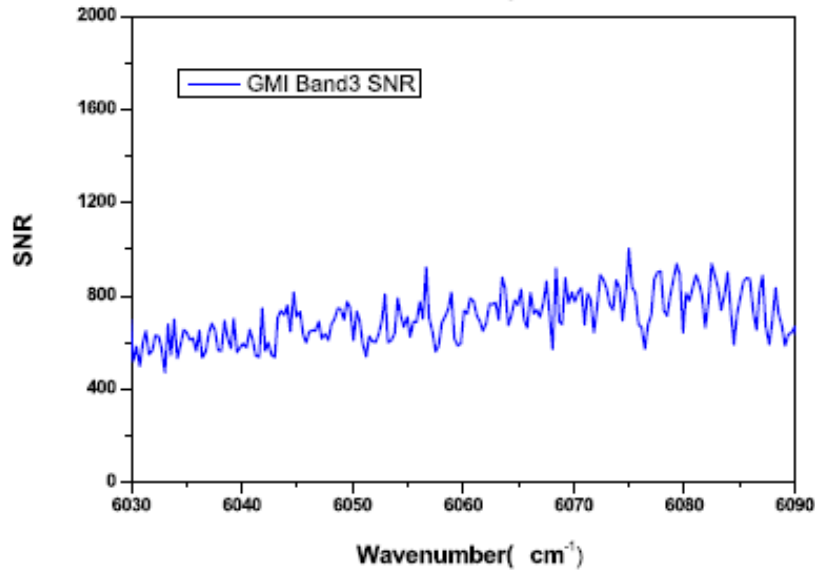
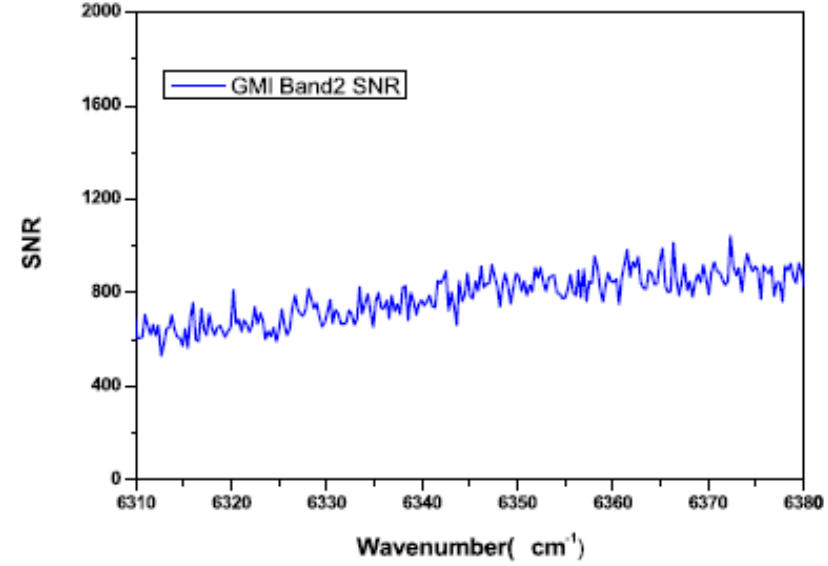
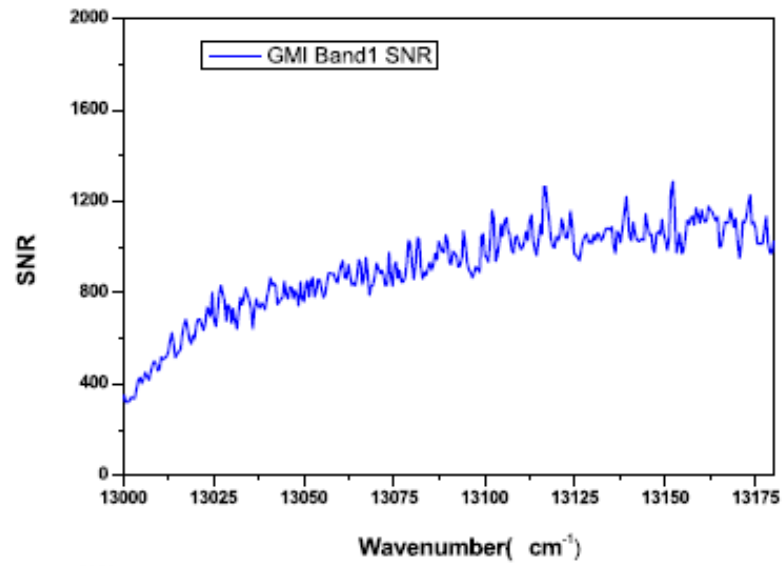
Spectral Resolution



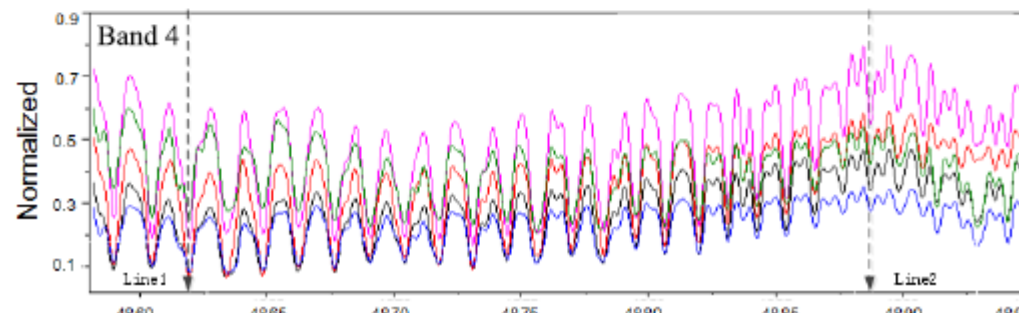
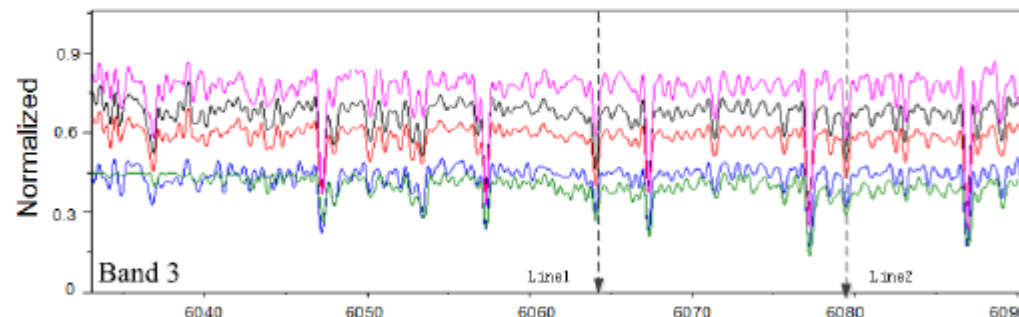
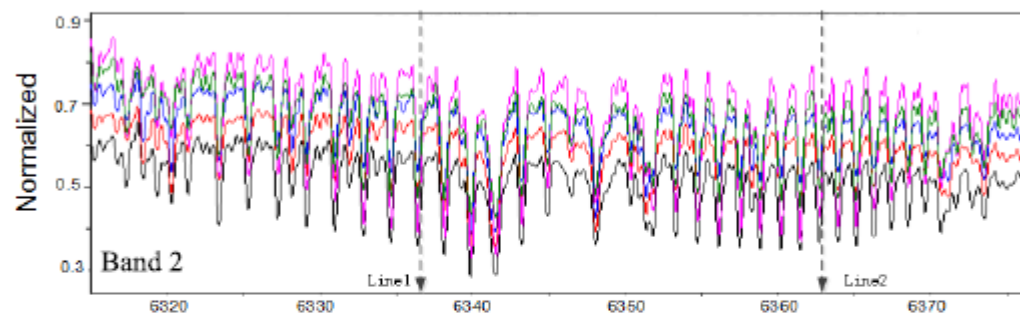
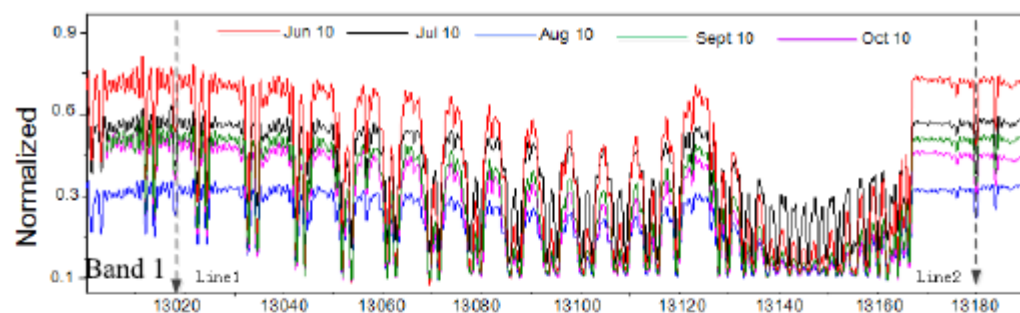
SNR



SNR



Spectral Stability

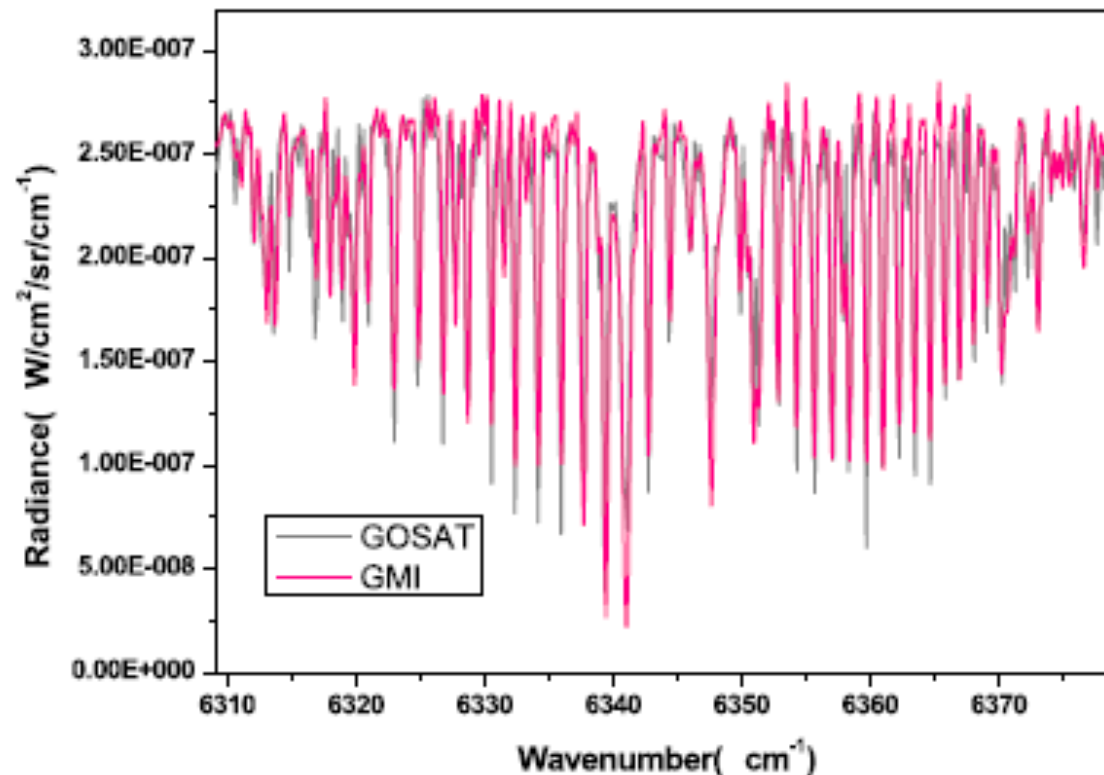


Wavenumber(cm^{-1})

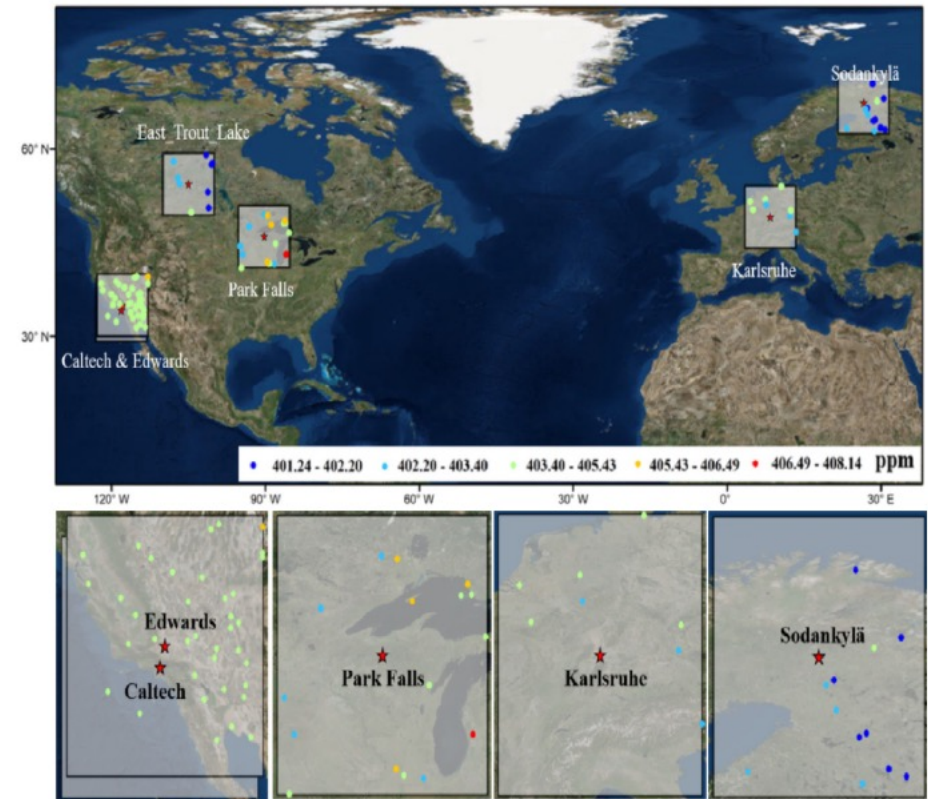
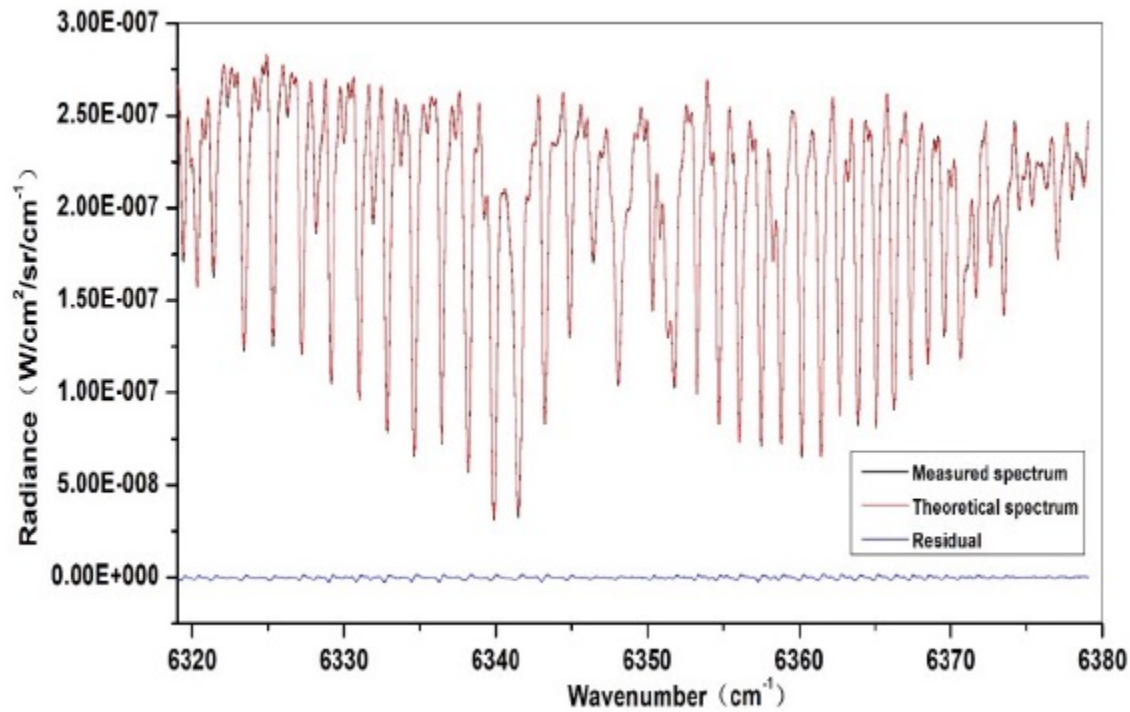
Time (2018)	Band 1 (cm^{-1})		Band 2 (cm^{-1})		Band 3 (cm^{-1})		Band 4 (cm^{-1})	
	Line 1	Line 2	Line 1	Line 2	Line 1	Line 2	Line 1	Line 2
Jun 10	13017.9790	13179.9970	6336.4353	6334.6466	6064.0515	6079.4725	4861.9178	4887.6720
Jul 10	13017.9900	13180.0270	6336.4363	6334.6536	6064.0415	6079.4736	4861.9245	4887.6520
Aug 10	13017.9900	13179.9970	6336.4363	6334.6536	6064.0515	6079.4746	4861.9245	4887.6520
Sept 10	13017.9900	13180.0270	6336.4473	6334.6436	6064.0445	6079.4857	4861.9245	4887.6554
Oct 10	13017.9900	13179.9970	6336.4363	6334.6536	6064.0515	6079.4857	4861.9111	4887.6654
Maximum deviation	0.0200	0.0300	0.0110	0.0102	0.0070	0.0130	0.0130	0.0200

L1 Product

The independent absorption lines are consistent, and the difference in radiation brightness is small. However, the spectral resolution of the two instruments is not the same, so there is a certain difference in the depth of the absorption peak

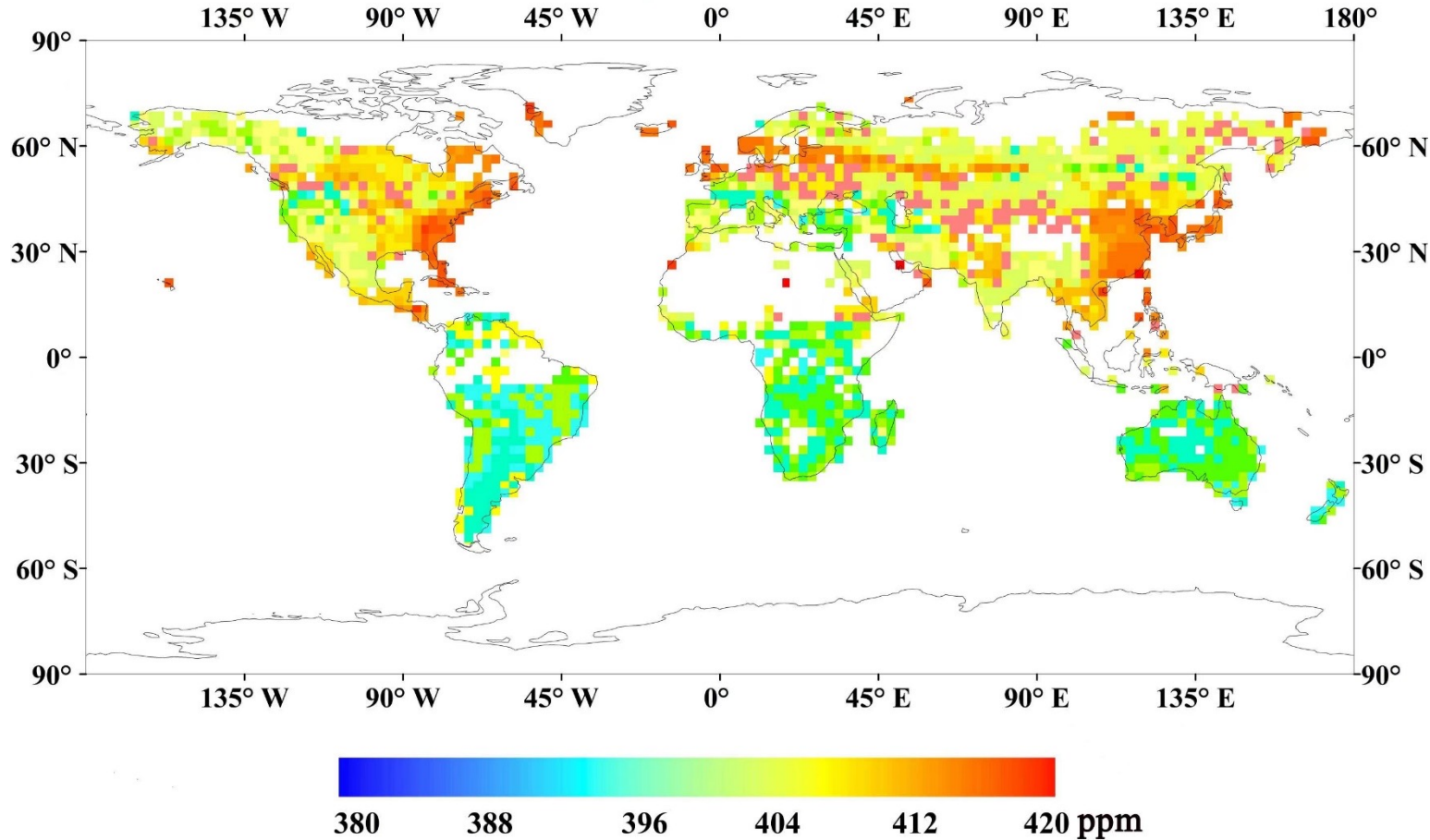


$$x_{i+1} = x_a + (K_i^T S_\varepsilon^{-1} K_i + S_a^{-1})^{-1} K_i^T S_\varepsilon^{-1} \times [y - F(x_i) - K_i(x_i - x_a)]$$



TCCON verification stations and GMI observation points

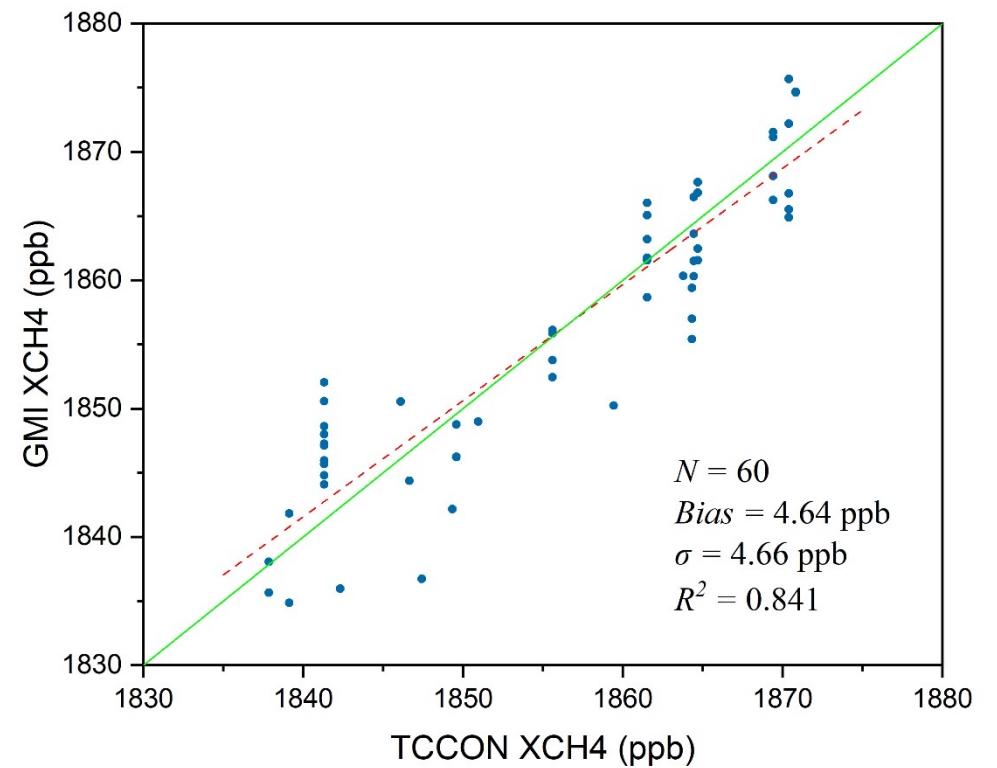
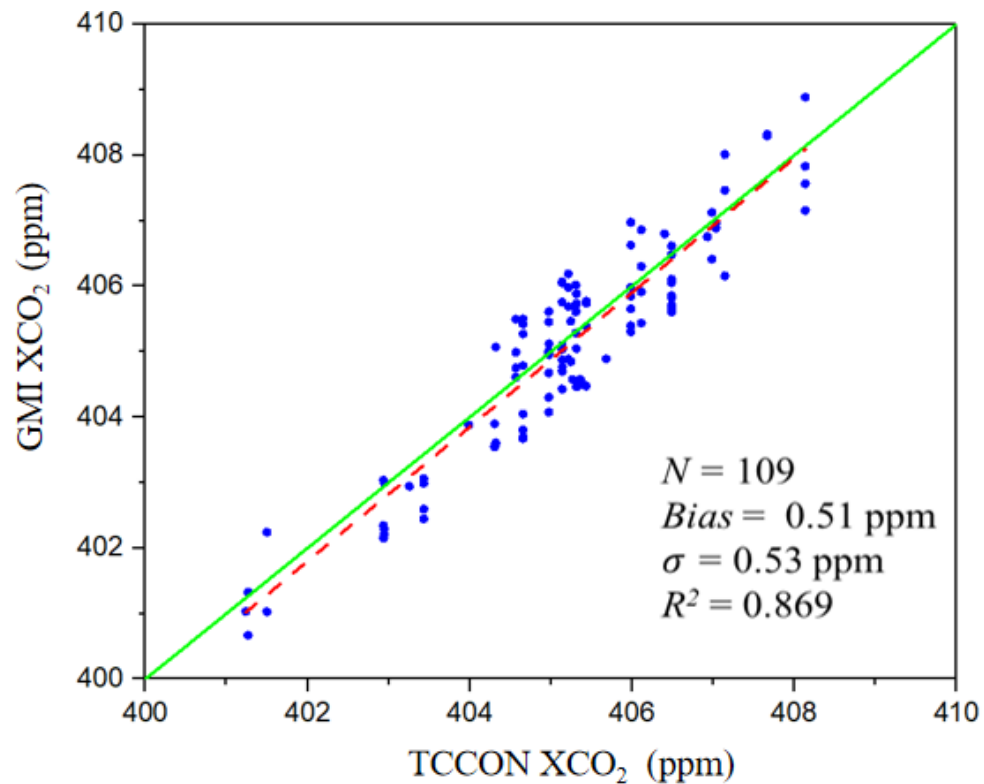
GMI XCO₂



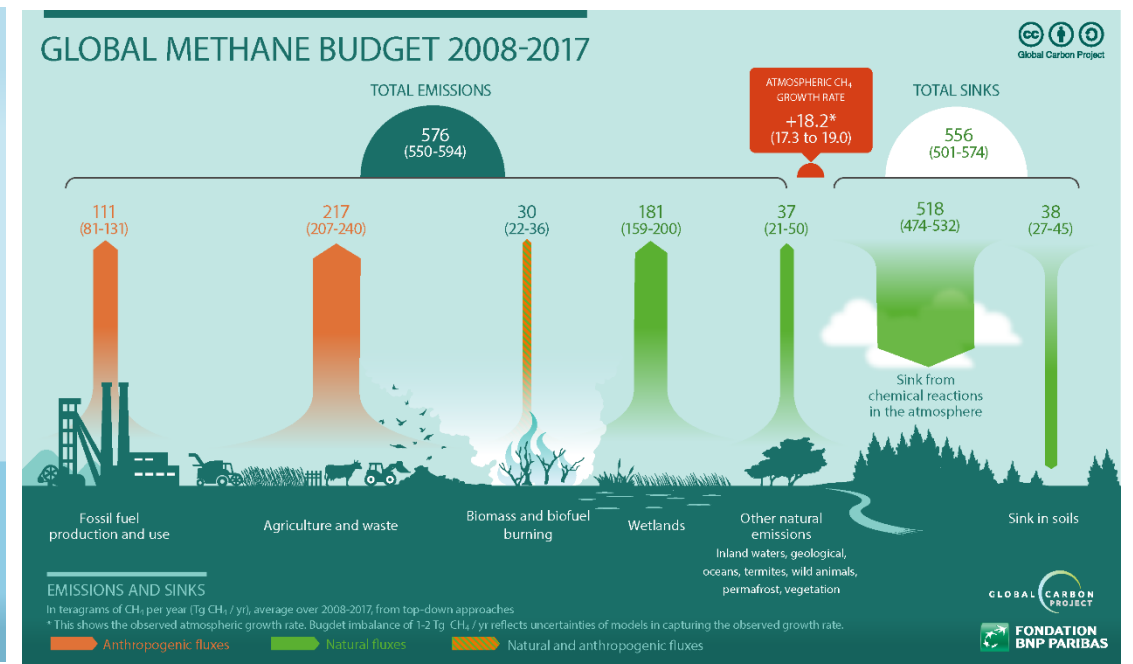
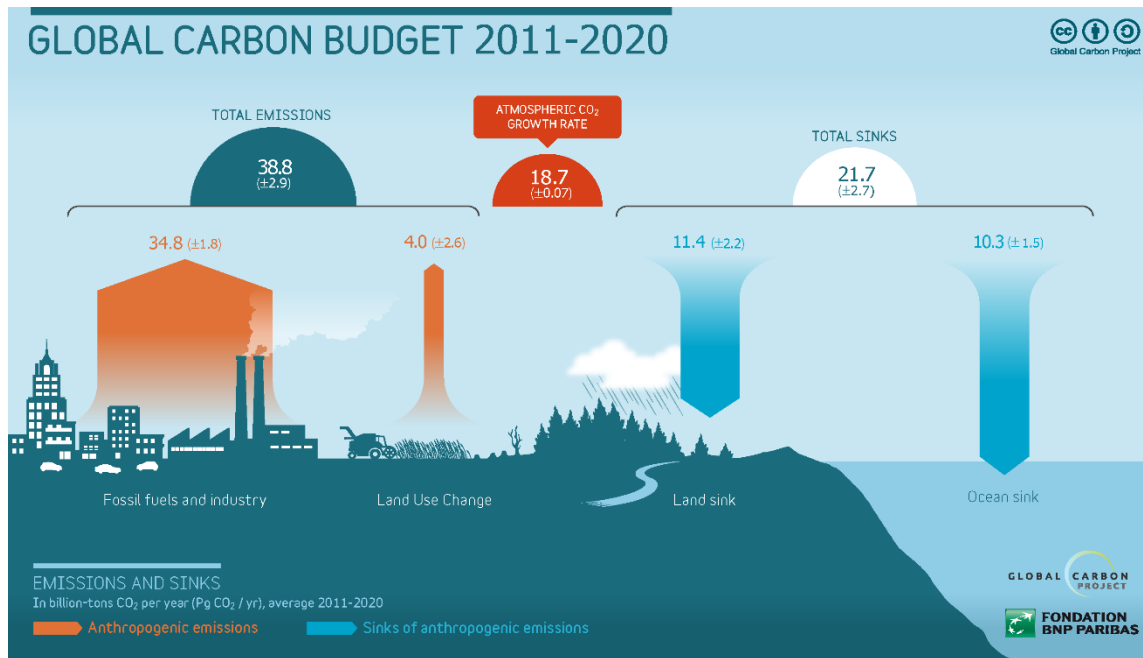
The GMI global atmospheric CO₂ measurement results in spring basically cover the land area within the latitude of 70°, and have a good manifestation of the difference of CO₂ concentration between the northern and southern hemispheres. Due to the influence of vegetation in the northern hemisphere in summer, the CO₂ concentration in the northern hemisphere is often higher than that in the southern hemisphere.

$$Bias = \frac{\sum_{j=1}^N x_j - X_j}{N}$$

$$\sigma = \sqrt{\frac{\sum_{j=1}^N (x_j - X_j - Bias)_j^2}{N}}$$



- Enhance the collaborative application of greenhouse gas monitor load GMI and aerosol detector load DPC data on Gaofen 5 satellite;
- Use actual GMI and DPC data to verify the theory, as well as perform performance analysis of the combination of the two technologies under different environments.



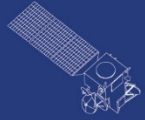
ESA /Copernicus Missions	No. Scenes
1. Sentinel-2	ftp
2. ERA-5	ftp
3. TCCON	ftp

ESA Third Party Missions	No. Scenes
1. MODIS	ftp
2. GOSAT	ftp
3. OCO-2	ftp

Chinese EO data	No. Scenes
1. GF5-01	ftp
2. GF5-02	ftp

Name	Institution	Poster title	Contribution including period of research
Sha Lu	Netherlands Institute for Space Research	Simultaneous Retrieval of Trace Gases, Aerosols, and Cirrus Using RemoTAP—The Global Orbit Ensemble Study for the CO2M Mission	<p>this study evaluates the performance of the Remote sensing of Trace gas and Aerosol Product (RemoTAP) algorithm based on synthetic orbit measurements of realistic atmospheric and geophysical scenes over land. To make use of the added value of the multi-angle polarimeter (MAP) aboard the CO2M mission, the RemoTAP algorithm is developed to perform simultaneous retrieval of trace gas and aerosol properties from both MAP and CO₂ imager (CO2I) measurements.</p>

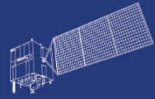
Name	Institution	Poster title	Contribution including period of research
Hanhan Ye	Hefei Institutes of Physical Science, Chinese Academy of Sciences	<p>Hanhan Ye, Hailiang Shi, Xianhua Wang, Erchang Sun, Chao Li, Yuan An, Shichao Wu, Wei Xiong, Zhengqiang Li & Jochen Landgraf (2023) Improving atmospheric CO₂ retrieval based on the collaborative use of Greenhouse gases Monitoring Instrument and Directional Polarimetric Camera sensors on Chinese hyperspectral satellite GF5-02, Geo-spatial Information Science, DOI: 10.1080/10095020.2023.2238773</p>	<p>We combined the Directional Polarimetric Camera (DPC) data on the same satellite to improve the anti-interference ability of GMI CO₂ retrieval and ensure its retrieval precision.</p>



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HJ-1AB



CBERS



Gaofen



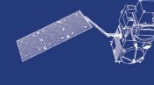
Beijing-2



Sentinel-1



Sentinel-2



Sentinel-3



Sentinel-5p



Aeolus

Thank you!