A coupled BRDF CO_2 retrieval method for the GF-5 GMI and improvements in the correction of atmospheric scattering

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The Greenhouse Gases Monitoring Instrument (GMI), on board the Chinese Gaofen-5 (GF-5) satellite, provides rich observation data for the global remote sensing of atmospheric CO_2. To meet the high-precision satellite retrieval needs of atmospheric CO_2, we designs a coupled bidirectional reflectance distribution function (BRDF) CO_2 retrieval (CBCR) method, which describes the surface reflectance characteristics by the BRDF, corrects for atmospheric scattering based on full physics retrieval theory, and ensures the stable retrieval of multiple parameters and atmospheric CO_2 by enriching prior constraints. Theoretical analysis shows that the influence of atmospheric scattering induced by the surface bidirectional reflectance characteristics is significantly related to the aerosol optical depth, solar zenith angle, and viewing zenith angle. The validation of GMI CO_2 retrievals shows that the CBCR method significantly reduced the influence of the surface bidirectional reflectance characteristics under high AOD and high SZA conditions, decreased the atmospheric CO_2 retrieval error from 0.58 ± 5.64 ppm to −1.33 ± 3.13 ppm, and increased the correlation with the temporal variation of actual atmospheric CO_2 from 34.7 to 76.8%. Our CBCR method can correct the influence of atmospheric scattering induced by the surface bidirectional reflectance characteristics on atmospheric CO_2 retrieval, and this work demonstrates that describing the surface reflectance characteristics by using BRDF is a promising idea in the field of satellite CO_2 retrievals.

1. Introduction

- **The Chinese GF-5 satellite GMI can provide an abundance of data for the global detection of atmospheric CO_2, was launched on 9 May 2018.**
- **GMI observes solar light reflected from the Earth's surface from near-infrared to the shortwave infrared region based on the spatial heterodyne spectroscopy technique.**

Table.1 Technical characteristics of the Greenhouse Gases Monitoring Instrument (GMI)

Parameter	Spectral Band			
	NIR	SWIR-1	SWIR-2	SWIR-3
Spectral range (nm)	759–769	1568–1583	1642–1658	2043–2058
Spectral resolution at FWHM (nm)	0.035	0.067	0.067	0.113
Signal-to-noise ratio (SNR)	300	300	250	250
Spatial resolution	10.5 km × 10.5 km			
Data coverage	August 2018 to April 2020			

2. Objective

- **Retrieve high-precision CO_2 products from GMI measurements.**
- **Improve initial retrieval algorithm which doesn't correct atmospheric scattering to obtain high retrieval accuracy and more effective observations.**

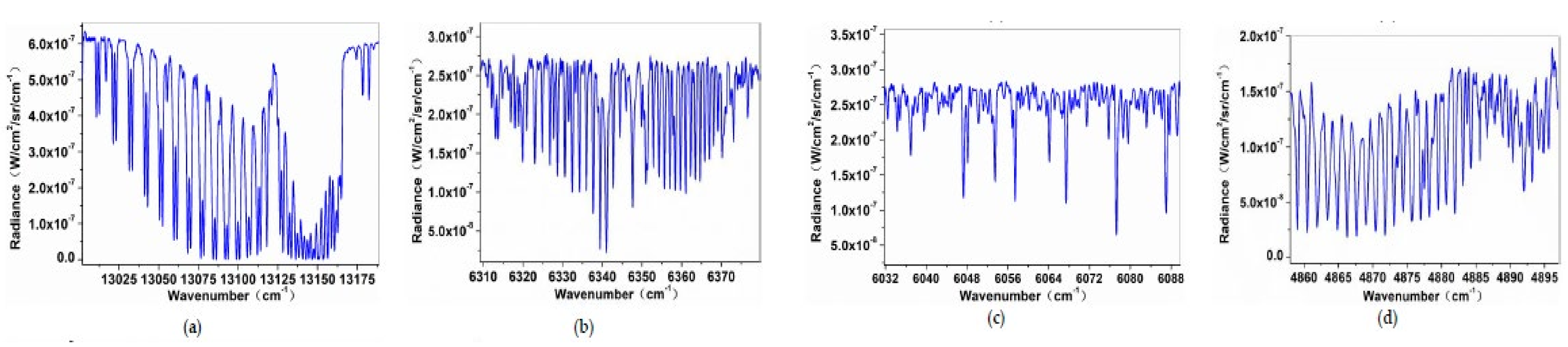
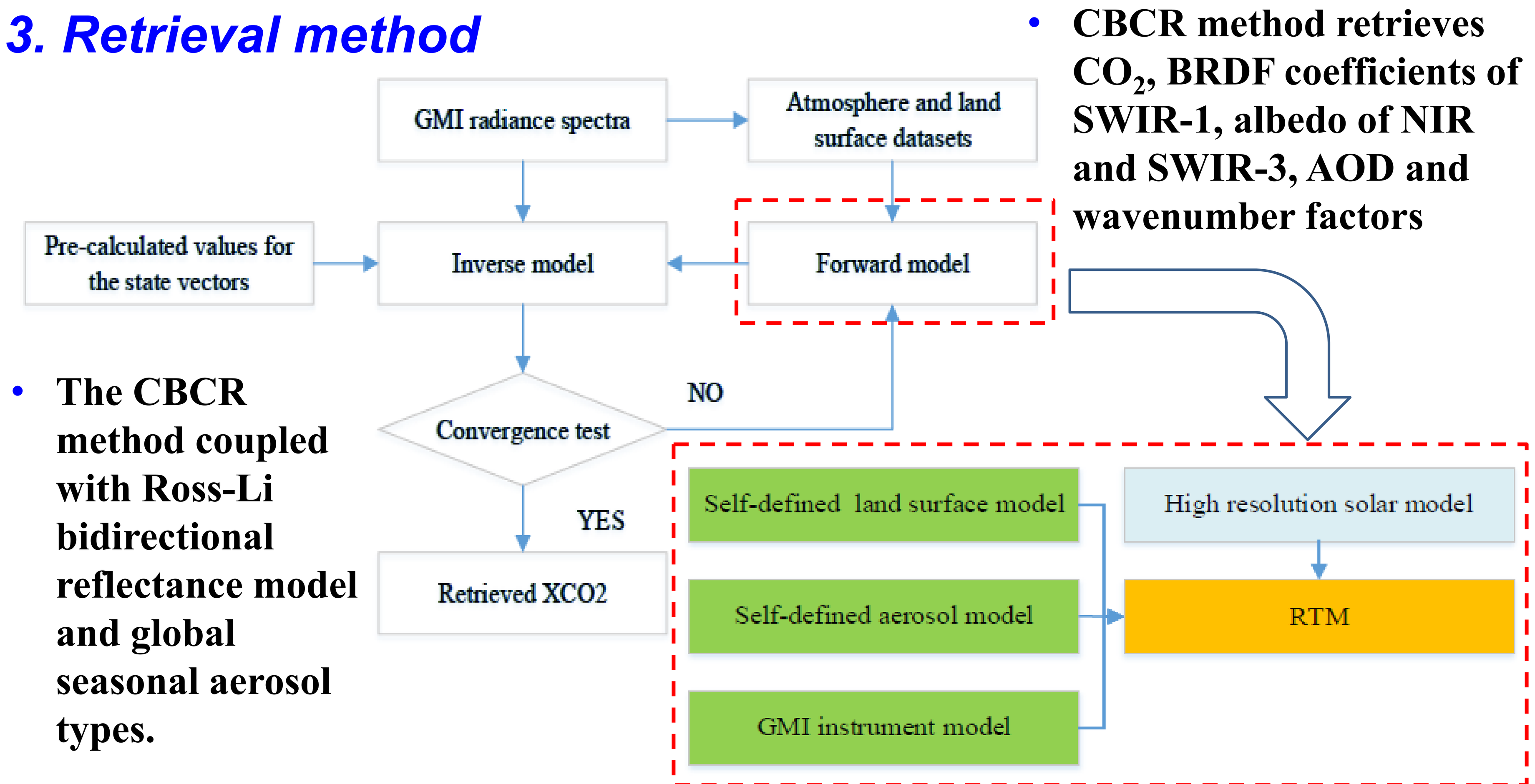


Fig.1 Spectra measured by GMI. Near-infrared (a), shortwave infrared-1, -2, and -3

3. Retrieval method



- **CBCR method retrieves CO_2, BRDF coefficients of SWIR-1, albedo of NIR and SWIR-3, AOD and wavenumber factors**
- **The CBCR method coupled with Ross-Li bidirectional reflectance model and global seasonal aerosol types.**

Surface model (kernel-driven bidirectional reflectance model)

$$\rho(\theta_i, \theta_v, \varphi; \lambda) = f_{iso}(\lambda)K_{iso} + f_{vol}(\lambda)K_{vol} + f_{geo}(\lambda)K_{geo}$$

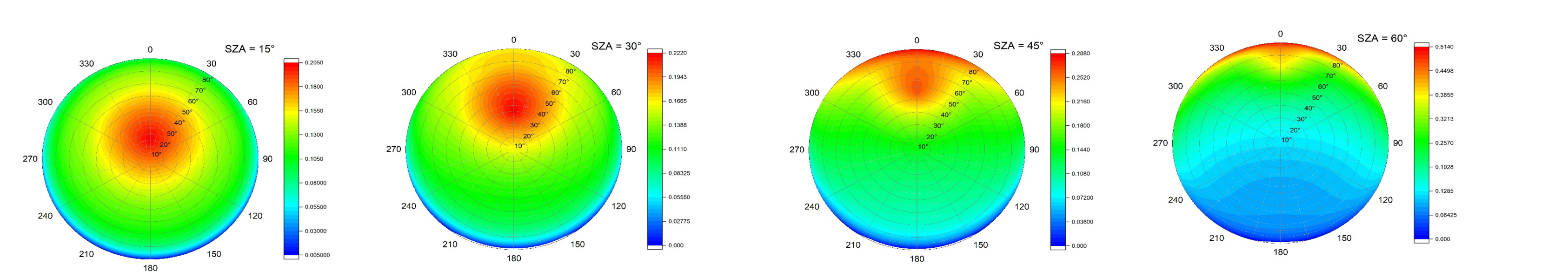


Fig.2 BRDF characteristic maps corresponding to the underlying urban surface in different solar zenith angles . 15° (a), 30° (b), 45° (c) and 60°

Aerosol model (11 aerosol components, four seasons)

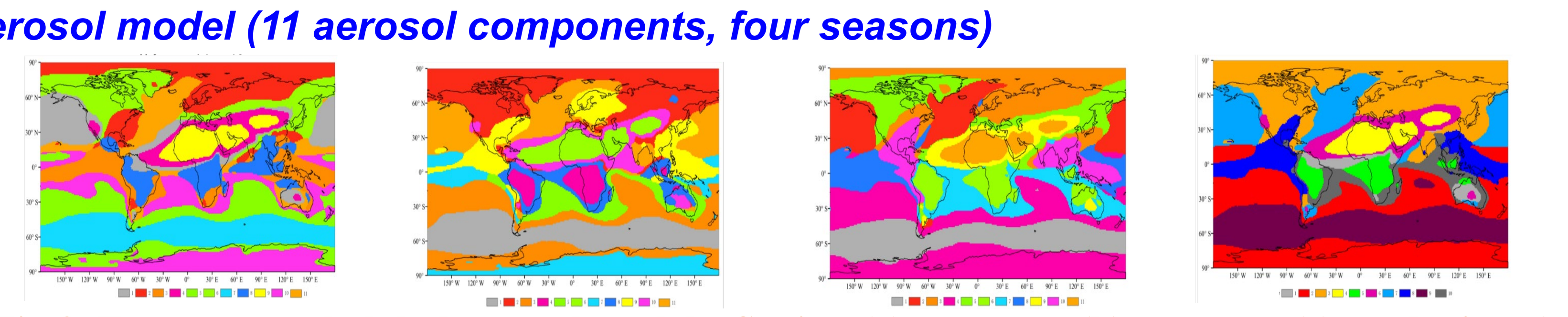


Fig.3 Four seasonal global aerosol models. Spring (a), summer (b), autumn (c), and winter)

4. Simulation results

- **The influence of surface bidirectional reflectance characteristics to XCO_2 retrievals is directionality and varies with AOD, 1 ppm under AOD 0.05 and 4.91ppm under AOD 0.4 (SZA<60°)**
- **The CBCR method can reduce the directionality of the retrieval error and improve the XCO_2 retrieval precision to 0.3ppm under AOD 0.05 and 2.2ppm under AOD 0.4.**

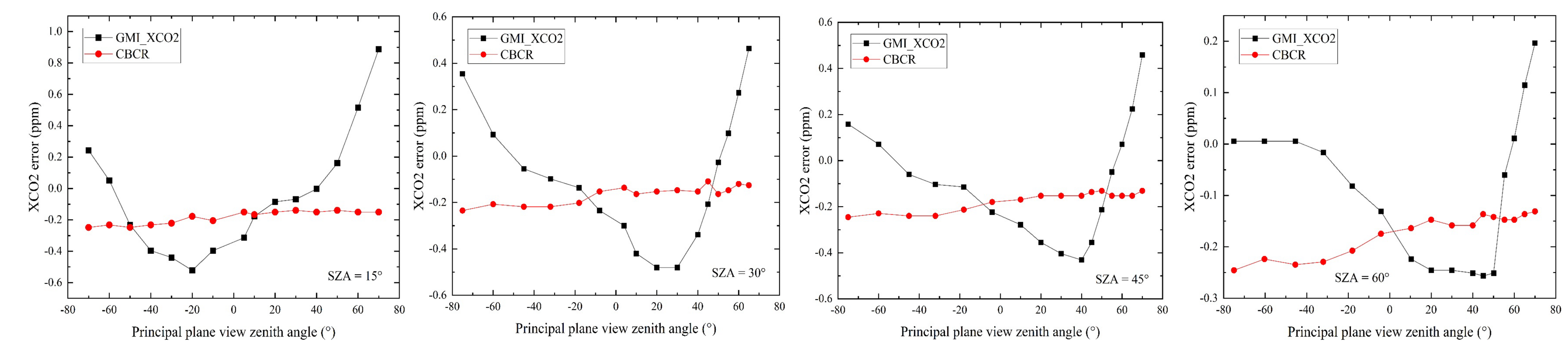


Fig.4 Results of GMI_XCO_2 and CBCR method under different observation conditions (AOD = 0.05)

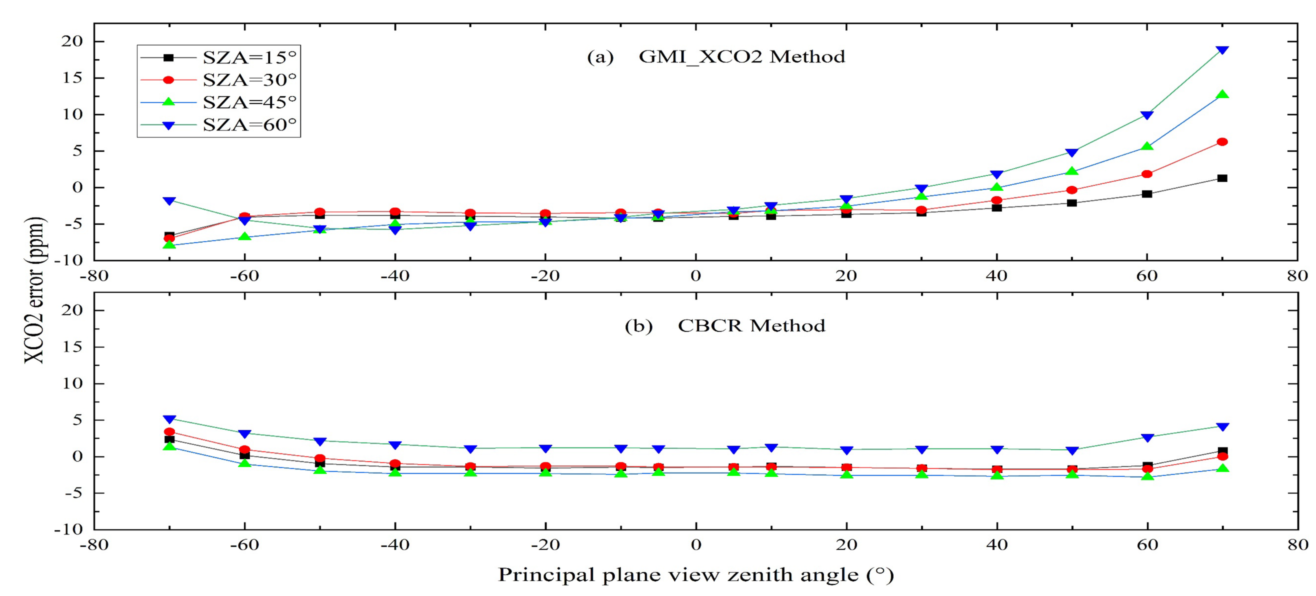


Fig.5 Retrieval errors of GMI_XCO_2 and CBCR under different observation conditions (AOD = 0.4)

5. Validation

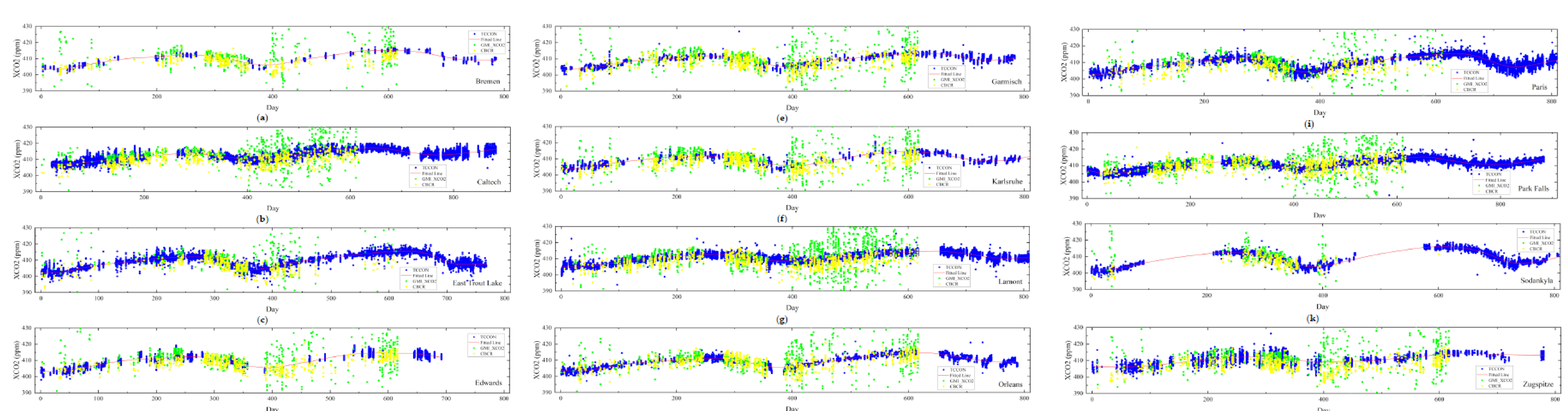


Fig.6 The GMI_XCO_2 and CBCR method results and the results of 12 TCCON sites

- **With the CBCR method we obtained GMI XCO_2 products with retrieval error 3.13ppm and high temp-spatial consistent with TCCON stations, with maximum of 3.3 ppm, a minimum of 2.43 ppm, and a maximum difference of only 0.87 ppm.**
- **The CBCR method reduces the correlations of CO_2 retrieval errors to the AOD and SZA.**

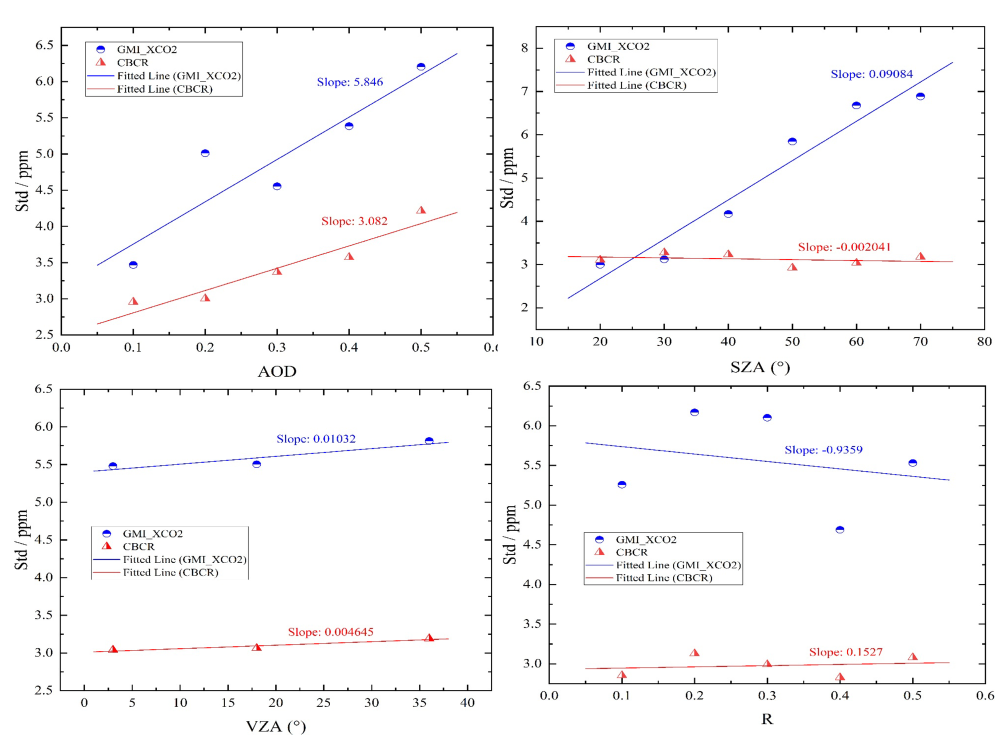


Fig.7 Correlation of atmospheric CO_2 retrieval deviation with AOD, SZA, VZA, and reflectance

6. Conclusions

- **With the CBCR method we obtained GMI XCO_2 products with retrieval error 3.13ppm.**
- **The CBCR method can reduce the directionality of CO_2 retrieval error and significantly reduces the influence of surface bidirectional reflectance characteristics under high AOD and high SZA.**