Estimation of CO_2 Column Retrieval Errors from Ignoring 1.6μm Polarization Calculation in Forward Modeling for Space-Bore Polarization-Sensitive Instruments

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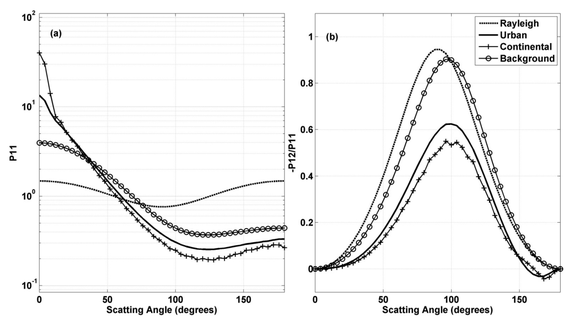
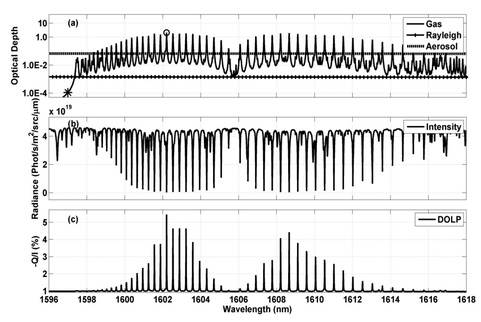
1 Introduction

Reflected sunlight in the near infrared 1.6μm band, observed by OCO-2 and Chinese TanSat, can be used to drive CO_2 information. Accuracy retrieved results from this region need to consider the light scattering by air molecules and aerosols. In addition, the polarization effects due to aerosols has great effect to the measurement radiation (see in Fig. 1.). But the full vector radiation transfer calculation can be too time consuming for real-time data processing. So can we use only the scalar radiation transfer calculation in the forward modeling?



①Aerosol Scattering Phase Matrix P_{11} and $-P_{21}/P_{11}$ at 1.6μm.



② Forward model simulation at 1.6μm band.
(a) optical depth; (b) Intensity; (c) DOLP (Q/I)

Fig. 1 Aerosol Polarization effect

1.1 Questions:

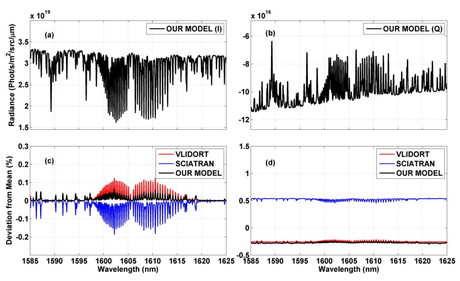
How much of the radiation error is made by a scalar approximation in this band?
How much of the CO_2 retrieval error is from neglecting polarization calculation in forward modeling?

1.2 Our Work:

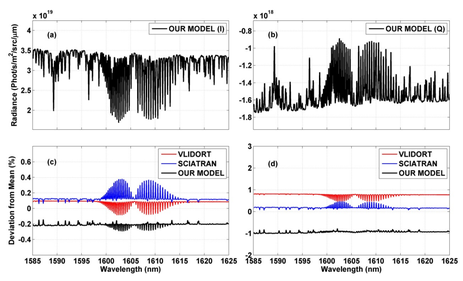
(1)Develop a new polarized atmosphere radiative transfer model coupling with Jacobian matrix calculation.
(2)Radiance and Jacobian produced by our model are validated.
(3)Sensitivity studies are performed to estimate the radiation simulation errors from neglecting polarization.
(4)A linear errors estimation method is used to estimate the CO_2 retrieval errors from neglecting polarization.

2 New Model Validation

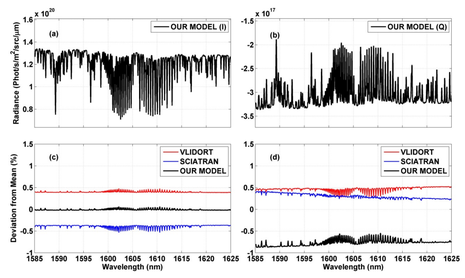
2.1 Radiance Validation by Comparing with VLIDORT and SCIATRAN.



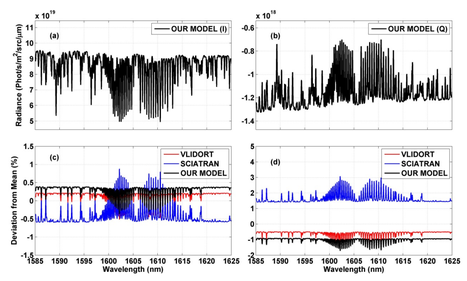
① Rayleigh only, SZA=60°, VZA=0.0°, SAZ=0.0°, VAZ=180°.
PS=950hPa, MaxPloc=0.9, Sigma=0.05, Albedo=0.1, US Stand.



② Background aerosol, SZA=60°, VZA=0.0°, SAZ=0.0°, VAZ=20°.
PS=980hPa, MaxPloc=0.9, Sigma=0.05, Albedo=0.1, AOD=0.6, US Stand.



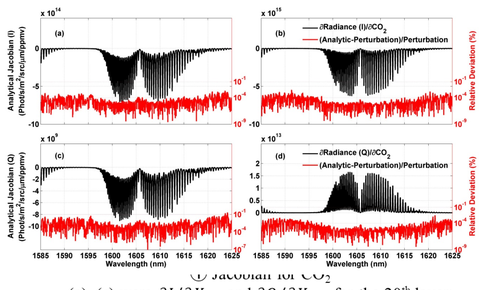
③ Continental Aerosol , SZA=45°, VZA=5.0°, SAZ=0.0°, VAZ=180°.
PS=950hPa, MaxPloc=0.9, Sigma=0.03, Albedo=0.3, AOD=0.3, US Stand.



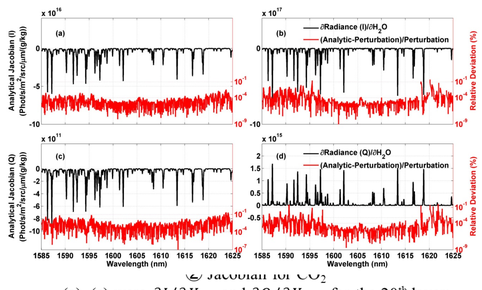
④Urban Aerosol, SZA=45°, VZA=30.0°, SAZ=0.0°, VAZ=45°.
PS=980hPa, MaxPloc=1.0, Sigma=0.05, Albedo=03, AOD=1.2, Tropical.

Fig. 2 Radiance calculation results validation. (VLIDORT and SCIATRAN are based on the Discrete Ordinate Method. Our model is relied on Doubling and Adding Method. The others input are same for the three models.).

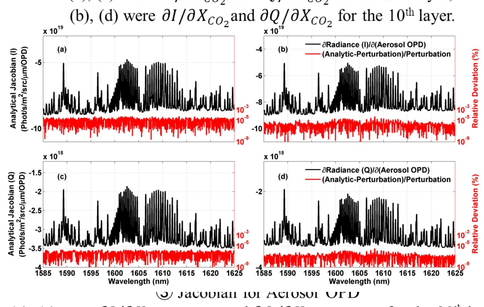
2.2 Jacobian Matrix Validation by Comparing with Perturbation Method.



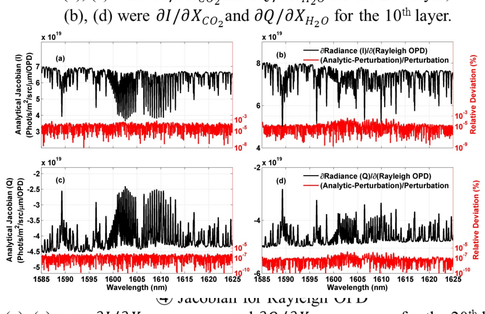
① Jacobian for CO_2
(a), (c) were $\partial I/\partial X_{CO_2}$ and $\partial Q/\partial X_{CO_2}$ for the 20th layer;
(b), (d) were $\partial I/\partial X_{CO_2}$ and $\partial Q/\partial X_{CO_2}$ for the 10th layer.



② Jacobian for CO_2
(a), (c) were $\partial I/\partial X_{CO_2}$ and $\partial Q/\partial X_{H_2O}$ for the 20th layer;
(b), (d) were $\partial I/\partial X_{CO_2}$ and $\partial Q/\partial X_{H_2O}$ for the 10th layer.



③ Jacobian for Aerosol OPD
(a), (c) were $\partial I/\partial X_{Aerosol\_OPD}$ and $\partial Q/\partial X_{Aerosol\_OPD}$ for the 20th layer;
(b), (d) were $\partial I/\partial X_{Aerosol\_OPD}$ and $\partial Q/\partial X_{Aerosol\_OPD}$ for the 15th layer.



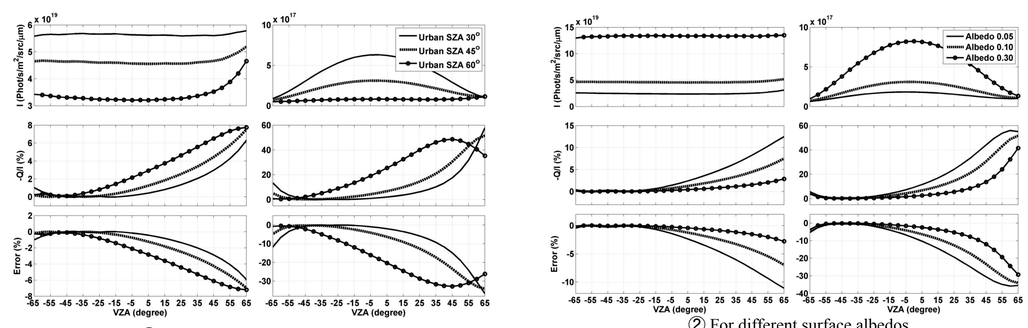
④ Jacobian for Rayleigh OPD
(a), (c) were $\partial I/\partial X_{Rayleigh\_OPD}$ and $\partial Q/\partial X_{Rayleigh\_OPD}$ for the 20th layer;
(b), (d) were $\partial I/\partial X_{Rayleigh\_OPD}$ and $\partial Q/\partial X_{Rayleigh\_OPD}$ for the 10th layer.

Fig. 3 Jacobian matrix validation. (The Continental aerosol case in Fig. 2 was used. In our model, the Automatic Differentiation technique is used to drive the Jacobian matrix, which is more efficient than the perturbation method.

3 Radiance Errors by Scalar Approximation

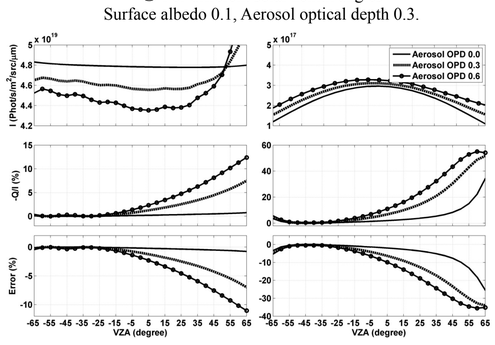
The OCO instrument is designed to measure only the radiation perpendicular to the incoming solar beam and the beam entering the instrument, expressed as I-Q. Neglecting polarization in the forward model simulation, the radiation error made by a scalar approximation can be expressed as:

$$Error = \left(\frac{I_S-(I-Q)}{I-Q}\right)\times 100 = \left(\frac{\frac{I_S}{I}}{1-\frac{Q}{I}}-1\right)\times 100 \qquad (1)$$



① For different solar zenith angles
Surface albedo 0.1, Aerosol optical depth 0.3.

② For different surface albedos.
Aerosol optical depth 0.3, Solar zenith angle 45°.



③ For different aerosol optical depths.
Surface albedo 0.1; Solar zenith angle 45°

Fig. 4 Variation of intensity, linear polarization and radiation errors if the polarization is neglected at 1597.0μm (window, left column) and 1602.204μm (strong absorption, right column) for different solar zenith angles, surface albedos and aerosol optical depths (Aerosol type is set to Urban.)

The results show that: except for some situations with very large observation angles, the radiation error made by a scalar approximation become larger with the solar zenith angle, aerosol optical depth increasing and the surface reflecting decreasing.

4 CO_2 Retrieval Error Estimation from Neglecting Polarization

The atmospheric CO_2 column information is coming from the ratio between the absorption line and window line I_{on_line}/I_{off_line}. The variation of the ratio value caused by neglecting the polarization can be use to estimate the CO_2 retrieval error.

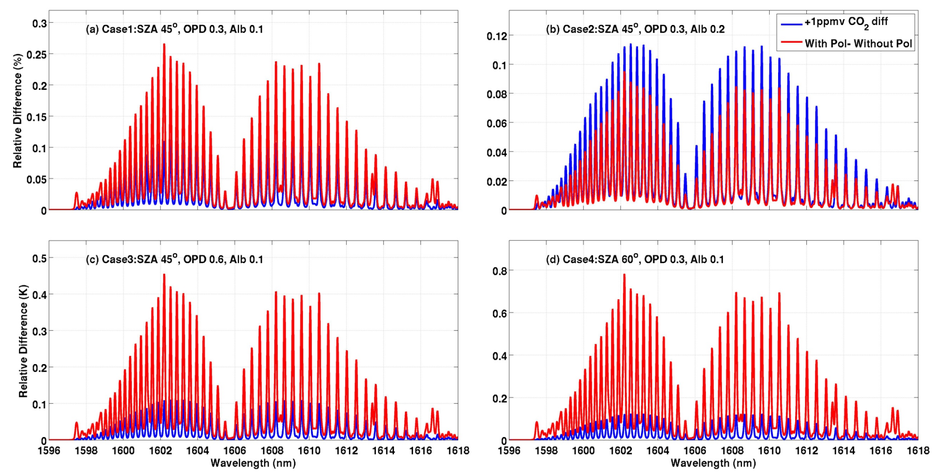
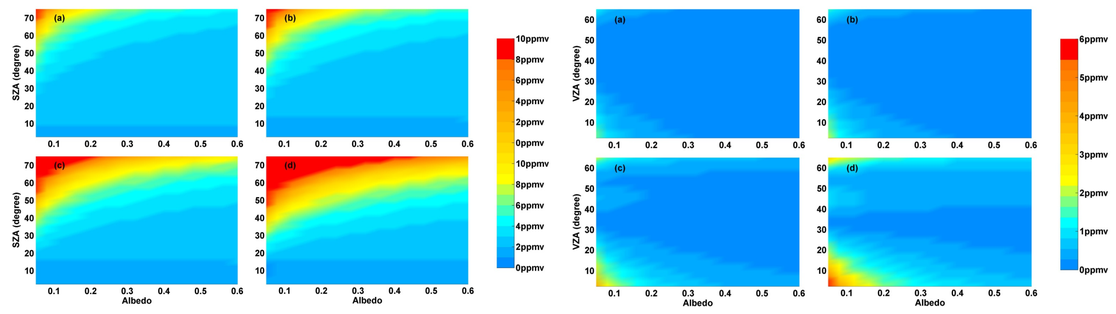


Fig. 5 The I_{on_line}/I_{off_line} ratio changing caused by neglecting polarization and 1$ppmv$ (about 0.25%) CO_2 profile shifting for different solar zenith angles, surface albedos and aerosol optical depths.



① Nadir view, CO_2 retrieval error under different surface albedos, solar zenith angles and aerosol optical depths. (X-axis is albedos, Y-axis is SZAs. (a), (b), (c), (d) were for aerosol optical depth 0.05, 0.1, 0.3 and 0.6.)

② SZA=45, CO_2 retrieval error under different surface albedos, view zenith angles and aerosol optical depths. (X-axis is albedos, Y-axis is VZAs. (a), (b), (c), (d) were for aerosol optical depth 0.05, 0.1, 0.3 and 0.6.)

Fig. 6 CO_2 column retrieval errors from ignoring the polarization in forward modeling by linear estimation.

5 Conclusion

CO_2 column retrieval errors from neglecting polarization calculation in 1.6μm band are largest when the solar zenith angle is high, the aerosol optical depth is large and surface reflectance is low. This error could be as high as 10ppmv, which is much larger than the required precision 1-2ppmv.

6 References and Acknowledgements

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