Retrieval of solar-induced chlorophyll fluorescence (SIF) from satellite measurements: comparison of SIF between TanSat and OCO-2

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Introduction

Solar-induced chlorophyll fluorescence (SIF) is emitted during photosynthesis in plant leaves. It constitutes a small additional offset to reflected radiance and can be observed by sensitive instruments with high signal-to-noise ratio and spectral resolution.

A hyper-spectrum grating spectrometer (ACGS) onboard the Chinese global carbon dioxide monitoring satellite (TanSat) provides high spectrum resolution ~0.038nm and signal-to-noise ratio (SNR) ~360 in O2-A band and it makes it possible to obtain SIF from space measurements with the best spatial resolution of 2 × 2 km^2.

In this study, One-year (March 2017–February 2018) of SIF data was retrieved from Orbiting Carbon Observatory-2 (OCO-2) and TanSat measurements using the Institute of Atmospheric Physics Carbon Dioxide Retrieval Algorithm for Satellite Remote Sensing (IAPCAS)/SIF algorithm.

Objectives

This study compares the retrieved SIF results from TanSat and OCO-2 spectra with the OCO-2 L2 Lite SIF product (OCO2_Level 2_Lite_SIF.8r) in a range of spatiotemporal scales to validate the IAPCAS/SIF algorithm and test the potential of multi-satellite SIF products in synergistic analysis.

Methods

Principle and Forward model

(1) The TOA spectral radiance (L^{λ}_{TOA}) at wavelength λ over Lambertian surface

$$L^{\lambda}_{TOA} = I^{\lambda}_{t} \cdot \mu_0 \cdot (\rho^{\lambda}_0 + \frac{\rho^{\lambda}_s \cdot T^{\lambda}_{\downarrow} \cdot T^{\lambda}_{\uparrow}}{\pi}) + F^{\lambda}_{TOA}$$

(2) Simplify the atmosphere scattering term by a low-order polynomial

$$L^{\lambda}_{TOA}(F^{\lambda}_{TOA}, \boldsymbol{a}) = < I^{\lambda}_{t} > \cdot \sum_{i=0}^{n} a_i \cdot \lambda^i + F^{\lambda}_{TOA}$$

(3) Express the spectral radiance formula above in logarithmic form

$$f\left(F^{rel}_{s}, \boldsymbol{b}\right) = log\left(< I_t + F^{rel}_{s} >\right) + \sum_{i=0}^{n} b_i \cdot \lambda^i$$

(4) SIF calculation

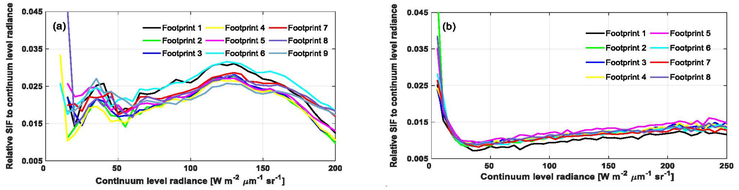
$$SIF = F^{rel}_{s} \cdot I_{cont}$$

Methods

Bias correction

A systematic bias due to instrument state or radiometric calibration remains in the raw SIF retrieval output if no bias correction is performed. The bias was considered to be related to the continuum level radiance and could be represented by a piecewise linear function between the continuum level radiance and the retrieved SIF offset from non-fluorescence measurements. The soundings marked as "snow and ice," "barren," and "sparsely vegetated" were chosen to construct the relationship function.

Bias correction curves from (a) TanSat on July 7, 2017, and (b) OCO-2 on June 16, 2017



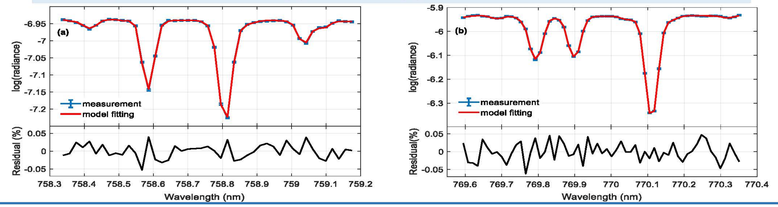
Data quality control

(1) SIF retrievals with reduced χ^2 (χ^2_{red}) values ranging from 0.7 to 1.3

(2) Continuum level radiance in the range of 15 ~ 200 W m^{-2} μm^{-1} sr^{-1}

(3) SZA < 60°

Fitted spectra and residuals for (a) 757 nm and (b) 771 nm windows of TanSat measurement



Conclusion

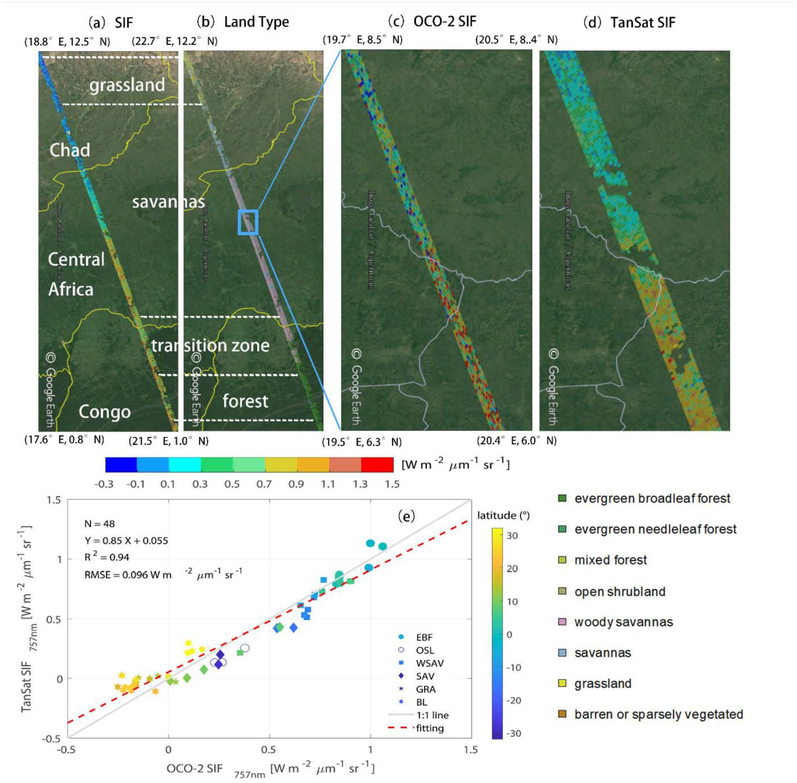
- The comparison between the IAPCAS/SIF results retrieved from OCO-2 spectra and the official OCO-2 SIF product shows a strong linear relationship ($R^2 > 0.85$) and suggests good reliability of the IAPCAS/SIF retrieval algorithm.
- SIF retrieved by IAPCAS/SIF from TanSat and OCO-2 shares the same spatial pattern for all seasons with gridded SIF difference less than 0.3 W m^{-2} μm^{-1} sr^{-1}.
- The retrieval uncertainty of seasonally gridded TanSat IAPCAS/SIF is less than 0.03 W m^{-2} μm^{-1} sr^{-1} whereas the uncertainty of each sounding ranges from 0.1 to 0.6 W m^{-2} μm^{-1} sr^{-1}.
- The spatio-temporal consistency between TanSat and OCO-2 and their comparable data quality enable joint usage of the two mission products.

Results

Validation of IAPCAS/SIF algorithm by comparison of OCO-2 SIF data at sounding scale

Number of soundings	R^2	RMSE/ W m^{-2} μm^{-1} sr^{-1}
211219-1097277	0.81-0.91	0.16-0.23

Inter-comparison of SIF between OCO-2 and TanSat at regional scale



Global distribution of seasonal TanSat SIF and the difference between OCO-2 and TanSat