Improvement and application of PPDF-S method for retrieving XCO_2 over aerosol dense areas

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1. Introduction

●GOSAT

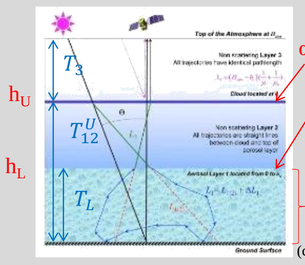
Greenhouse gases Observing SATellite (GOSAT) was launched in 23 January 2009 to measure atmospheric carbon dioxide (CO_2) and methane (CH_4) in the global scale. GOSAT measures solar radiation backscattered by the surface or atmosphere of the earth in Short-Wavelength InfraRed (SWIR) region, and column averaged concentrations of carbon dioxide (XCO_2) and methane (XCH_4) are retrived from the measured radiation.

●PPDF-S retrieval method

$$I(k) = I_0 T(k) = I_0 \int_0^\infty \exp(-kL)\, P(L)\, dL \quad \left(\int_0^\infty P(L)\, dL = 1\right)$$ (Bennartz and Preusker., 2006)

PPDF-S retrieval method (Oshchepkov et al., 2013)

PPDF parameters
- h: altitude of cloud/aerosol layer
- α: the relative reflection of the cloud/aerosol layer
- ρ: the mean path length under the cloud/aerosol layer
- γ: an adjustment parameter



ρ and γ allow for path length modification under the layer

(changed from Oshchepkov et al., 2009)

$$T_{eff} = \alpha_U T_3 + (1 - \alpha_U)\, T_{12}^U T_L T_3$$

$$T_{12}^U = exp\left[-C_\mu(1 + \delta_U)\tau_{12}\right]$$
$$T_L = (1 - \alpha_L)\, exp\left[-C_\mu \tau_L \delta_L\right] + \alpha_L exp\left[+C_\mu \tau_L\right]$$
$$T_3 = exp\left[-C_\mu \tau_3\right]$$

$$C_\mu = \frac{1}{cos\Theta}$$
$$\delta_U = \rho_U \cdot exp\left[-\gamma_U \cdot \tau_{12}\right]$$
$$\delta_L = \rho_L \cdot exp\left[-\gamma_L \cdot \tau_L\right]$$

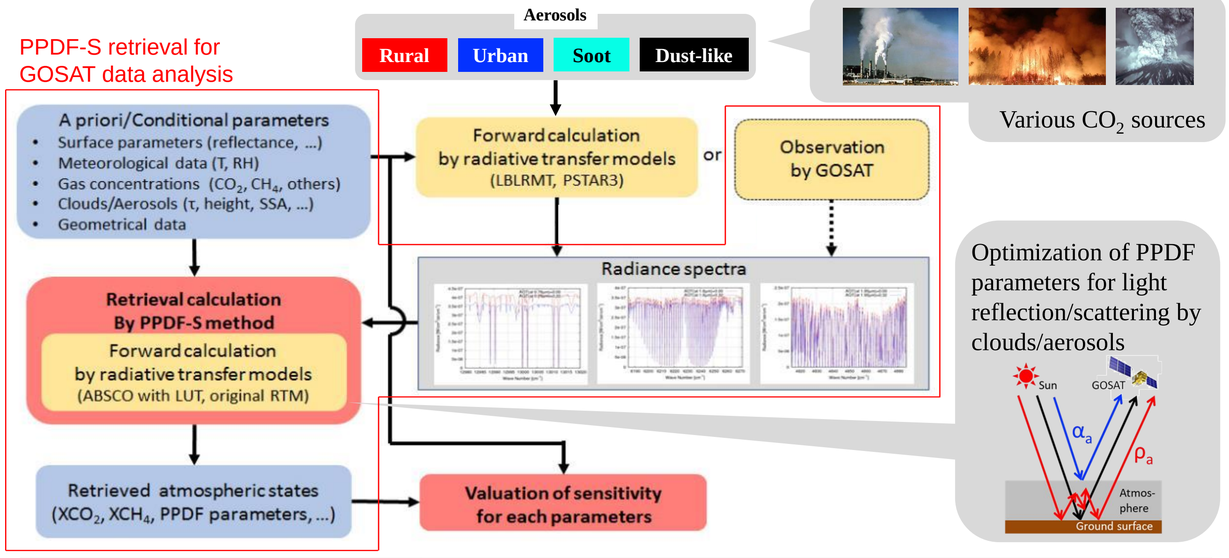
$$\tau_{12} = \int_0^{h_U} k(h)\, dh, \tau_L = \int_0^{h_L} k(h)\, dh, \tau_3 = \int_{h_U}^{H_{TOA}} k(h)\, dh$$

2. Study purposes

① To improve the PPDF-S algorithm and to tune its parameters under high aerosol conditions, as well as to evaluate the retrieval performance of the method through simulation studies

② To apply the improved PPDF-S algorithm and tuned parameters are applied to analyses of GOSAT data observed over Western Siberia during the biomass burning season

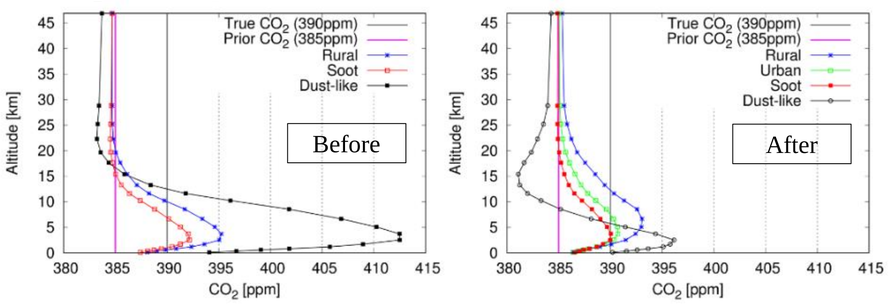
3. Study method



Model, Parameter	Details
Multiple scattering radiative transfer model	Polarization System for Transfer of Atmospheric Radiation3 (Pstar3)
Solar Irradiance Model	Band 1: Kurucz's model / Bands 2, 3: Toon's model
Zenith angle	Solar: 30° /Satellite: 0°
Surface albedo	0.05–0.50 (Bands 1, 2, 3)
Surface pressure	Grid Pointed Value (GPV) data of middle latitude summer from Japan Meteorological Agency (JMA)
Temperature and pressure profile	
Water vapor (H_2O) profile	
Carbon dioxide (CO_2) profile	390 ppm in all layers
Aerosol types	Dust-like Urban, Rural, Soot (volume mixing ratio is given at 0–2 km)
Aerosol Optical Thickness (AOT)	0.05–1.0
Gas absorption	Line-By-Line (LBL) calculation using HIgh resolution TRANsmission molecular absorption database (HITRAN) 2004
Instrumental Line Shape Function (ILSF)	Ver. 2011 provided by NIES

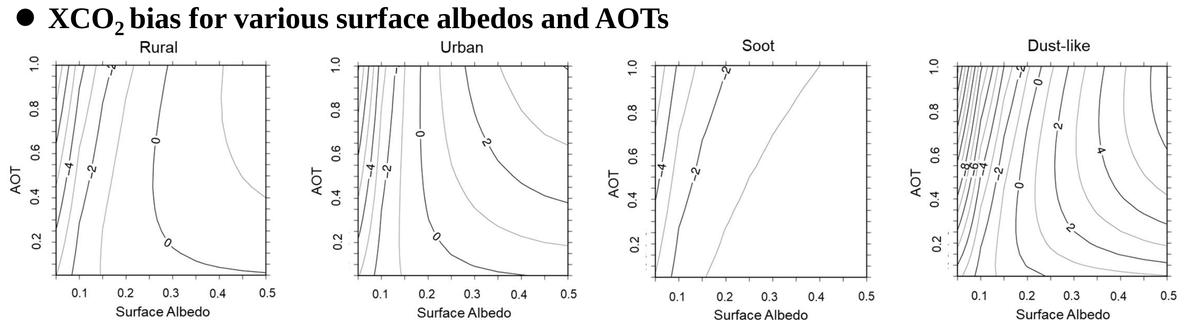
4. Simulation studies

● CO_2 vertical profile



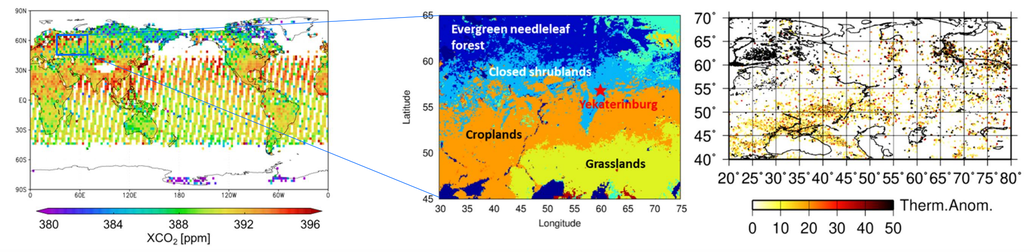
By **optimizing the constraint of α_a representing the light reflectance by aerosols**, it was possible to obtain a stable solution of XCO_2.

● XCO_2 bias for various surface albedos and AOTs



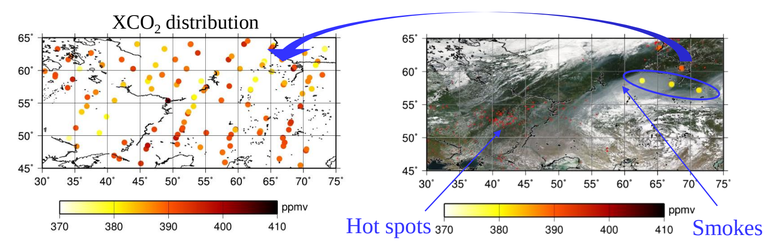
5. Application to Biomass Burning Area in Western Siberia

● Analysis area and period



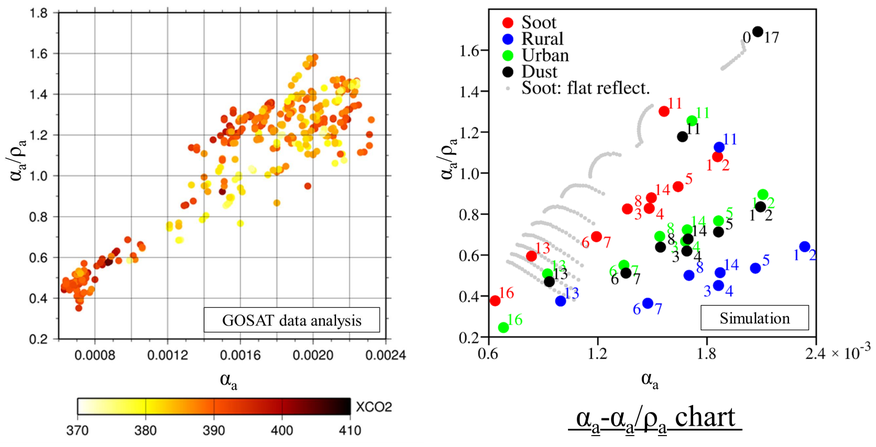
- **Area**: Selected Western Siberia area (45-65° N latitude, 30-75° E longitude; Western Siberia is a large biomass burnining area)
- **Period**: The summer (June–August) of 2013 (numerous fires and smoke plumes emitted from biomass burning were detected using a MODerate resolution Imaging Spectroradiometer (MODIS))

● XCO_2 newly retrieved after the optimization



The amount of data retrieved using the PPDF-S method increased by about 70%. In some cases, XCO_2 can be retrieved by the optimized method even over smoke from biomass burning.

● Identification of atmospheric aerosol types by PPDF parameters

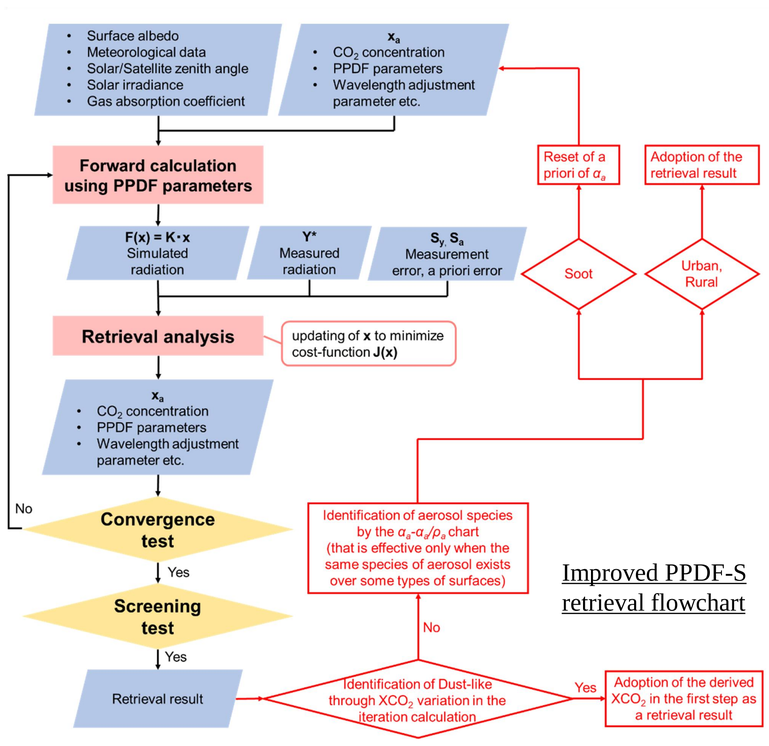


Land cover type: 0, water; 1, evergreen needleleaf forest; 2, evergreen broadleaf forest; 3, deciduous needleleaf forest; 4, deciduous broadleaf forest; 5, mixed forest; 6, closed shrublands; 7, open shrublands; 8, woody savanna; 9, savanna; 10, grasslands; 11, permanent wetlands; 12, croplands; 13, urban and built-up areas; 14, cropland/natural; 15, snow and ice; 16, barren or sparsely vegetated areas; 17, water bodies; and 18, tundra.

Its slope and absolute values are almost identical to those for the Soot-type aerosols in the simulation.
→ Soot aerosols were included in the atmosphere over the target area during the analysis period.

The α_a-α_a/ρ_a chart presents the possibility of identifying atmospheric aerosol types.

5. Further improved PPDF-S retrieval algorithm considering of the difference of light properties between aerosol types



Information of CO_2, aerosols and carbon monoxide (CO), which is newly observed by GOSAT-2 using the algorithm are expected to contribute to a better capability of distinguishing anthropogenic CO_2 emissions.

- **Large XCO_2 bias for Dust-like**
  The derived XCO_2 in the first step of the iterative calculation to minimize the cost function ***J(x)*** in the PPDF-S retrieval is closest to the true value for Dust-like aerosols.

- **Negative XCO_2 bias for Soot**
  It can result from underestimation of the effects of a shortened light-path length on the PPDF-S retrieval.
  Soot effect… Light scattering + Light absorption
  → A larger a priori value of α_a than the original value can represent the shortened light-path length and can reduce the XCO_2 bias.

6. Conclusions

- In the improved version of the PPDF-S retrieval methods, the constraint of a PPDF parameter that represents the light reflectance effect by aerosols (α_a) was optimized based on simulation studies.
- The optimization enabled to retrieve stable CO_2 profile under atmosphere including aerosols under the simulations. In the application of the optimized PPDF-S method for analysis of GOSAT data measured in Western Siberia, the retrieval came to be executable, even under smoky conditions, and the total number of retrieved data increased by about 70%.
- We proposed the improved PPDF-S retrieval algorithm considering of the difference of light properties between aerosol types using the optimized PPDF parameters. The further improved algorithm is anticipated for application to the analysis of GOSAT-2 data to retrieval CO2, aerosols and CO simultaneously, which are expected to contribute to a better capability of distinguishing anthropogenic CO_2 emissions.

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