PPDF-based method to account for atmospheric light scattering in spectroscopic observation of GHG from space

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History of the method

1. The developments of this method was initiated by Inoue-san and Yokota-san in 2005

2. The main goal was to develop rapid and precise GOSAT data processing

3. To develop this alternative method we had a small team within GOSAT Project at NIES including DHF staff

4. Currently, the PPDF-based product is available at the NIES GOSAT website
Content of the talk

1. Theoretical background of the PPDF-based algorithm.

2. Validation of CO$_2$ retrievals using ground-based TCCON measurements and comparison with other algorithms
PPDF-based methodology
What is the essence of PPDF-based method?

Both PPDF and FPh solutions are completely equivalent by accuracy.
The simplest case refers to non-scattering atmosphere.

\[ R = \frac{\mu}{\pi} S^0 \cdot \Gamma \cdot \exp\left\{-\left( L \sigma C_{gas} \right)^* \right\} \]
The general case of multi-layered scattering atmosphere

\[ T_{1,2,...,n} = \int \int \cdots \int \exp(-k_1L_1 - k_2L_2 - \cdots - k_nL_n) P^{(12\ldots n)}(L_1, L_2, \ldots, L_2) \, dL_1, dL_2, \ldots, dL_n \]
Two versions of PPDF model

Two layer model

Three layer model

These layers refer to effects of light path modification only, we consider arbitrary number of gas layers
An example of PPDF parameterization using two layered atmosphere

\[
P(L_1, L_2) = \begin{cases} 
  P_1(L) = \alpha \cdot \delta(L) + (1 - \alpha)P_1^*(L), & h \leq h_e \\
  P_2(L) = \delta(L - L_2), & h_e < h \leq h_a,
\end{cases}
\]

\[
R \sim \iint_{L_1, L_2} \exp(-k_1L_1 - k_2L_2)P(L_1, L_2)dL_1dL_2
\]

\[
\tilde{T} = \alpha T_2 + (1 - \alpha)T_1T_2,
\]

\[
T_1 = \exp \left[-\left(\frac{1}{\mu} + \frac{1}{\mu_0}\right) \cdot (1 + \delta) \cdot \tau_1 \right] \quad T_2 = \exp \left[-\left(\frac{1}{\mu} + \frac{1}{\mu_0}\right) \tau_2 \right]
\]

\[
\tau_1 = \int_0^{h_e} k(h)dh, \quad \tau_2 = \int_{h_e}^{h_2} k(h)dh, \quad \delta = \rho \cdot \exp\{-\gamma \cdot (\tau_1 + \tau_2)\}, \quad \mu = \cos \Theta
\]

this parameterization was derived using Monte-Carlo simulation of Solar radiative transfer in the atmosphere.
A simple illustrative example what is PPDF

In absence of aerosol and clouds PPDF is delta function because only pathlength L exists. Light scattering by aerosol and cloud could both decrease and increase the light path depending on the surface albedo. Both of these effects lead to broadening of the PPDF

Four PPDF parameters:

- $h$ is the effective layer altitude
- $\alpha$ is the relative aerosol or cloud reflection
- $\rho$ is PPDF half-width
- $\gamma$ characterize PPDF asymmetry
Two versions of PPDF-based retrievals

PPDF-D
screens out those satellite observations that are significantly contaminated by atmospheric light scattering using only oxygen A-band
Then simple DOAS technique retrieves gas amount

PPDF-S
Accounts for atmospheric light scattering by simultaneous gas and light path retrievals from all bands. As a result, the number of GOSAT soundings available for the processing are substantially increased as compared with previous version (PPDF-D)
Advantages to be emphasized

Rapid data processing
due to limited aerosol and cloud spectral calculation.

If … with FP we do not need spectral calculations at each individual line ↓
PPDF formalism deals with only one PPDF for each of the three bands ↓

PPDF Parameterization
is optimal because it describes the net effect of ALS

Connection between PPDF and FPh is available
Validation of XCO$_2$ retrievals using ground-based TCCON measurements
Global location of the total Carbon Column Observing Network (TCCON)

GOSAT single scans were selected over 12 TCCON stations
GOSAT-TCCON coincidence criteria

- **Temporal averaging**: both GOSAT and TCCON soundings were weakly mean.
- **Spatial averaging**: data fall within 5° radius circle centered at each TCCON station.
- **TCCON data**: within ± 1h of the GOSAT overpass time.
- **GOSAT data**: around 2 years of GOSAT operation from June 2009.
GOSAT-TCCON XCO$_2$ correlation diagrams for all five algorithms

Generally, GOSAT XCO$_2$ PPDF-S retrievals look well. At least, it provided the lowest bias and standard deviation as compared with TCCON data.

- **NIES V2.00**: $a = 1.03$, $N_c = 1149$, $Bias = -1.74$ ppm, $\sigma = 2.04$ ppm, $r = 0.83$
- **ACOS B2.10**: $a = 0.85$, $N_c = 1467$, $Bias = -0.71$ ppm, $\sigma = 1.83$ ppm, $r = 0.80$
- **NIES PPDF-S**: $a = 0.95$, $N_c = 1260$, $Bias = 0.06$ ppm, $\sigma = 1.89$ ppm, $r = 0.81$
- **UoL FP: 3G**: $a = 0.91$, $N_c = 1347$, $Bias = 0.44$ ppm, $\sigma = 2.60$ ppm, $r = 0.72$
- **RemoTeC V2**: $a = 1.04$, $N_c = 1631$, $Bias = -2.32$ ppm, $\sigma = 2.10$ ppm, $r = 0.80$
Seasonal trends of GOSAT retrievals around Izaña site

This site has an unique location for providing validation of satellite-based measurements. Here we could expect strong dust aerosol both over dark (ocean) and bright (Western part of Sahara desert) surfaces.
Seasonal trend of XCO$_2$ for five algorithms over Sahara desert

The retrievals - blue colors, red - FTS measurements, green ATM

Generally, all algorithms reproduce the seasonal cycle well, PPDF-S provides the largest observation number available for the processing.

- **N$_S$=2607**
- **N$_S$=2547**
- **N$_S$=3249**
- **N$_S$=1303**
- **N$_S$=543**
GOSAT single scan counters distributed by PPDF parameters from different algorithms

Percentage numbers at the corner of each panel characterize the part of GOSAT observation under very small level of ALS (PPDFs<0.04)
Basic PPDF publications


One more PPDF presentation at poster session

Poster Session 1 (Day 2 (June 4, 2019) 12:30 - 13:45)
Topic 2. Retrieval Algorithms and Uncertainty Quantification

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17. Improvement and Application of PPDF-S Method for Retrieving XCO2 over Aerosol Dense Areas (C. Iwasaki, Univ. Tokyo, Japan)