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**

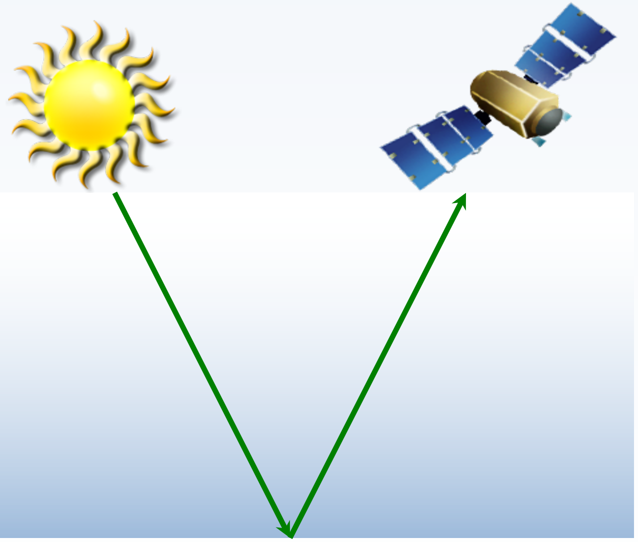
Content of the talk

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

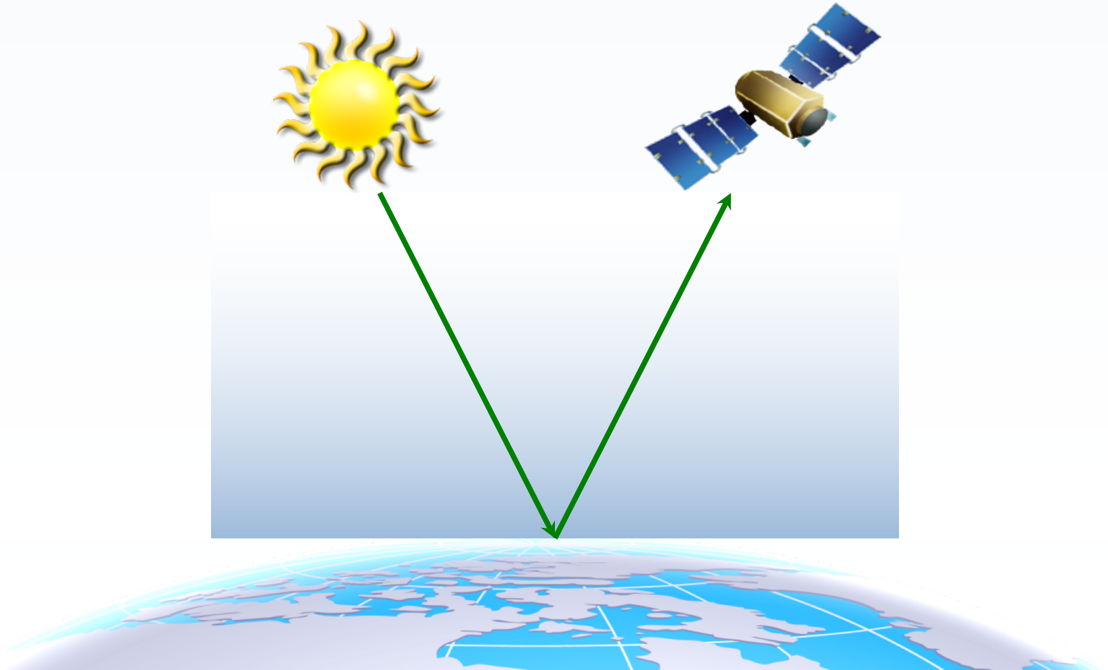
What is the essence of PPDF-based method?



Both PPDF and FPh solutions are completely equivalent by accuracy

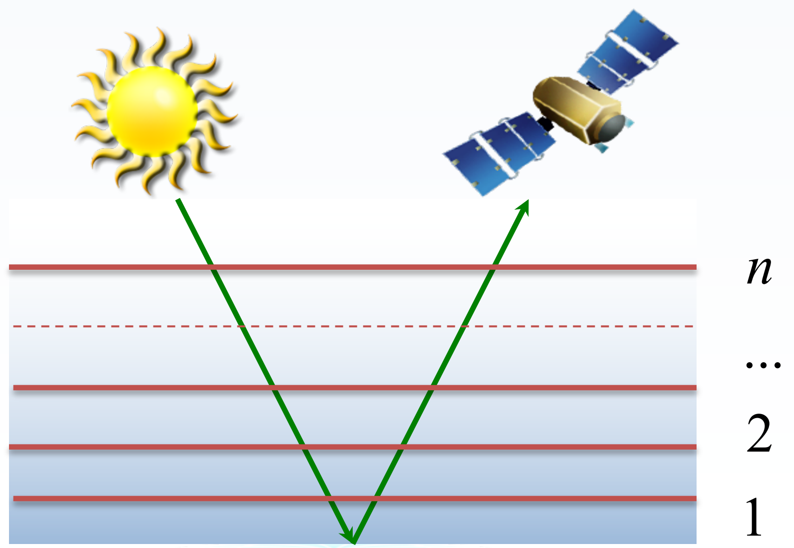
The simplest case refers to non-scattering atmosphere

$$R = \frac{\mu}{\pi} S^0 \cdot \Gamma \cdot \exp\{-(\, \boldsymbol{L}\, \sigma C_{gas}\}^*$$



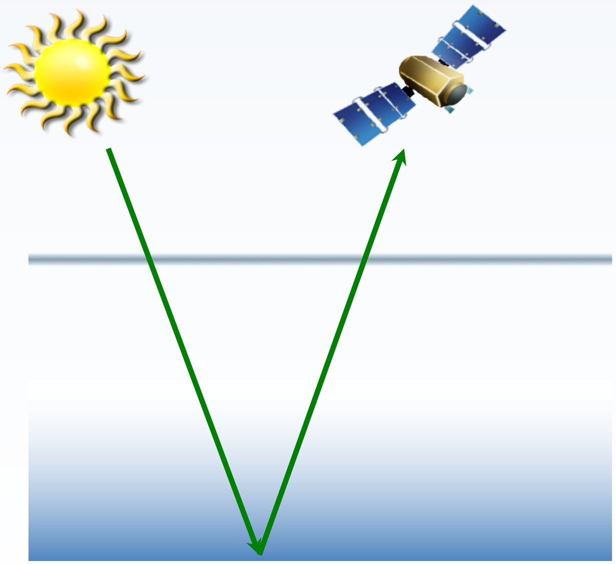
The general case of multi-layered scattering atmosphere

$$T_{1,2,...n} = \iint\limits_{L_1L_2...} ... \int\limits_{n} \exp\left(-k_1L_1 - k_2L_2 - ... - k_nL_n\right) P^{(12...n)}\left(L_1, L_2, ...L_2\right) dL_1, dL_2, ..., dL_n$$

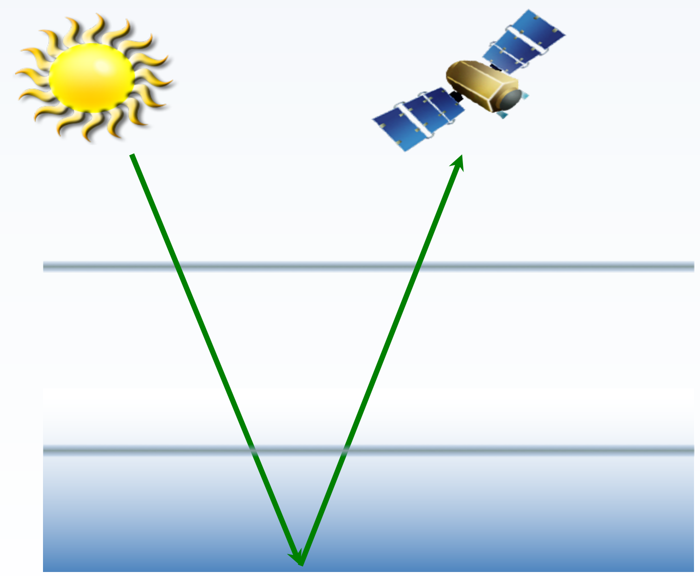


Two versions of PPDF model

Two layer model



Three layer model



These layers refer to effects of light path modification only, we consider arbitrary number of gas layers

This is

An example of PPDF parameterization using two layered atmosphere

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

$$R \sim \iint_{L_1, L_2} \exp(-k_1 L_1 - k_2 L_2) P(L_1, L_2) dL_1 dL_2$$

$$\tilde{T} = \alpha T_2 + (1-\alpha) T_1 T_2,$$

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

$$\tau_1 = \int_0^{h_c} k(h) dh, \ \tau_2 = \int_{h_c}^{h_a} k(h) dh, \ \delta = \rho \cdot \exp\{-\gamma \cdot (\tau_1 + \tau_2)\}, \ \mu = \cos\Theta$$

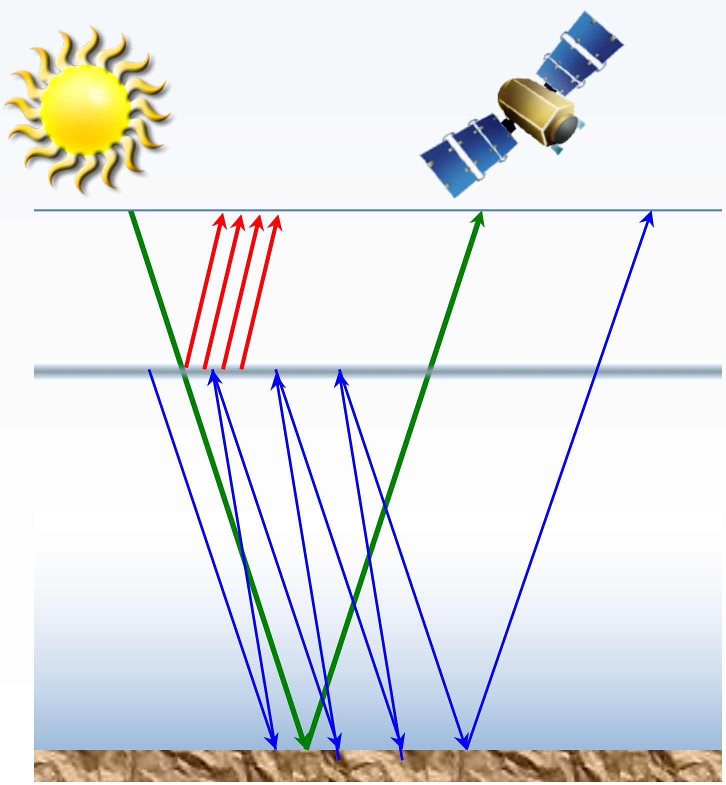
this parameterization was derived using Monte-Carlo simulation of Solar radiative transfer in the atmosphere.

A simple illustrative example what is PPDF

In absence of aerosol and clouds PPDF is delta function because only pathlength L exists.

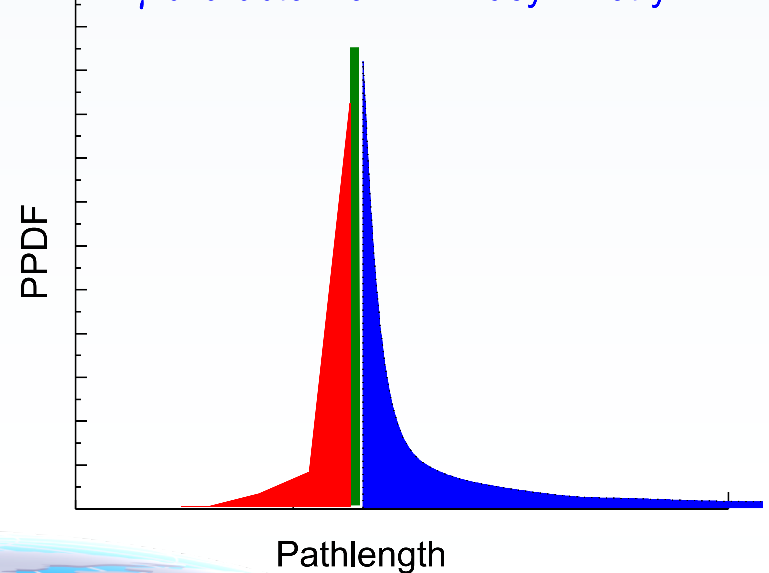
Light scattering by aerosol and cloud could both decrease↓ and increase↓ the light path depending on the surface albedo.

Both of these effects lead to broadening of the PPDF



Four PPDF parameters:

- *h* is the effective layer altitude
- α is the relative aerosol or cloud reflection
- ρ is PPDF half-width)
- γ characterize PPDF asymmetry



Two versions of PPDF-based retrievals

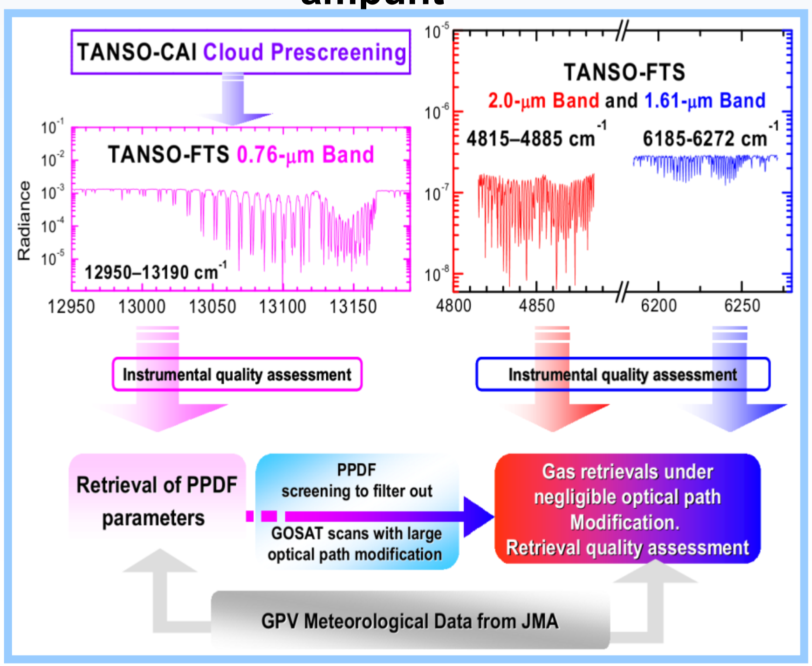
by setup for PPDF and gas retrievals

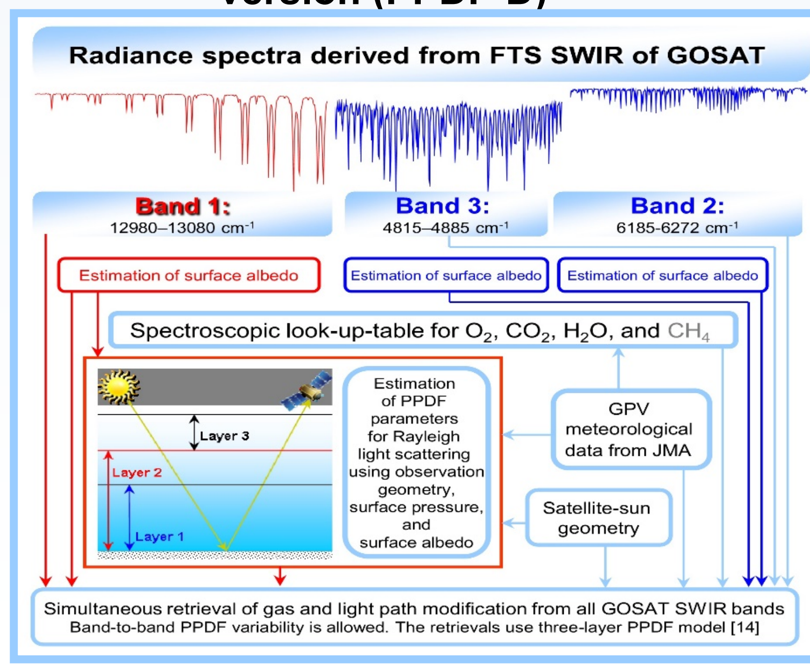
PPDF-D

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

PPDF-S

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

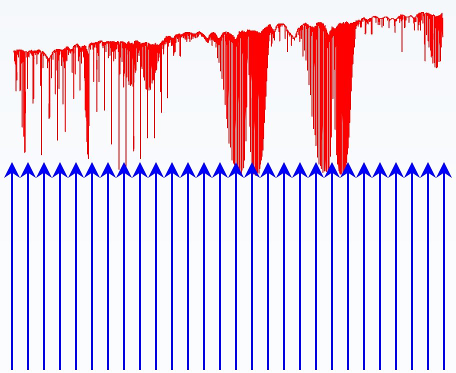




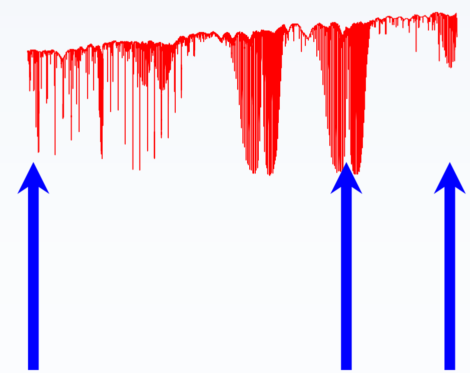
Advantages to be emphasized

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

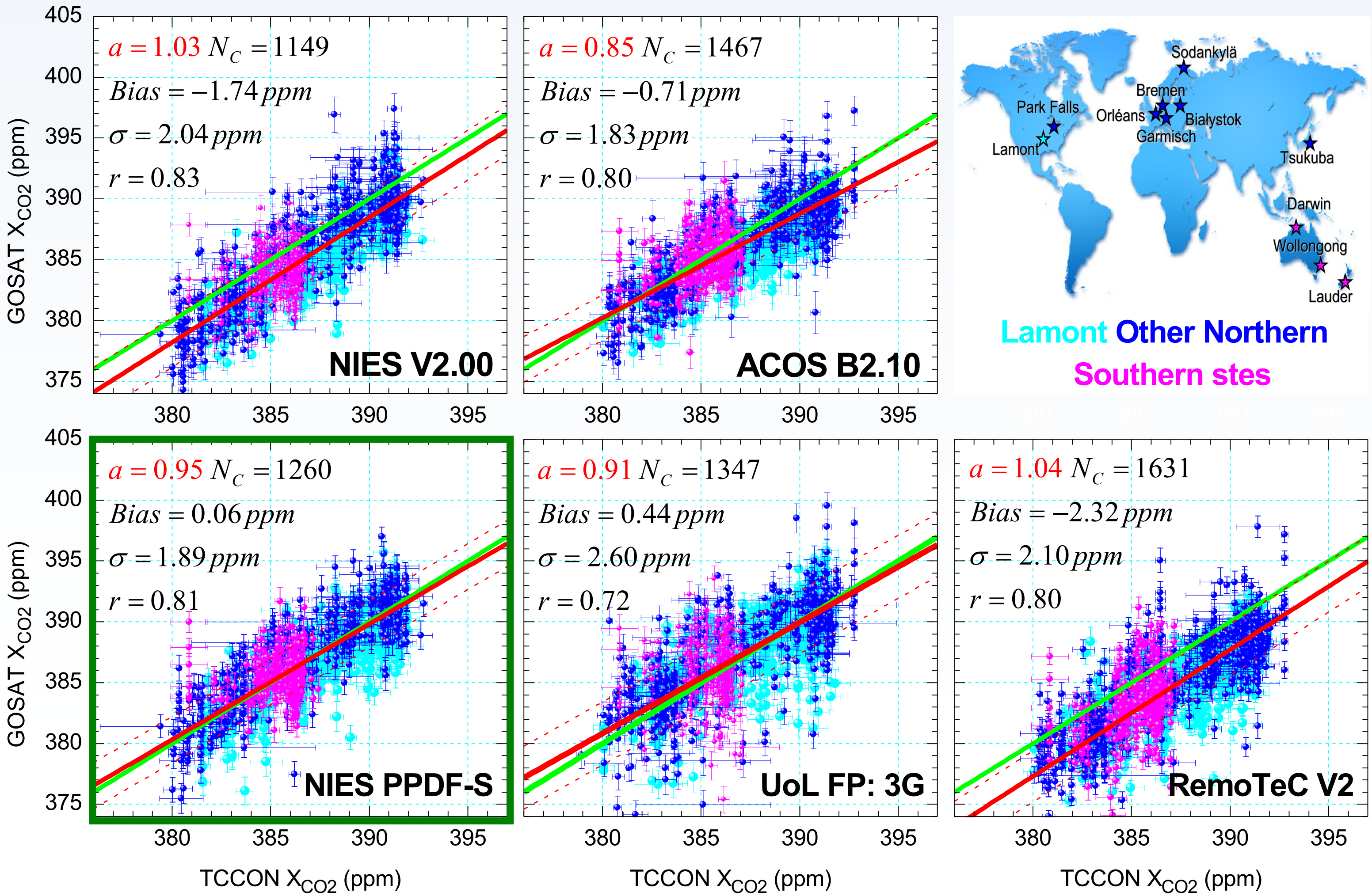
GOSAT-TCCON coincidence criteria

- **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.

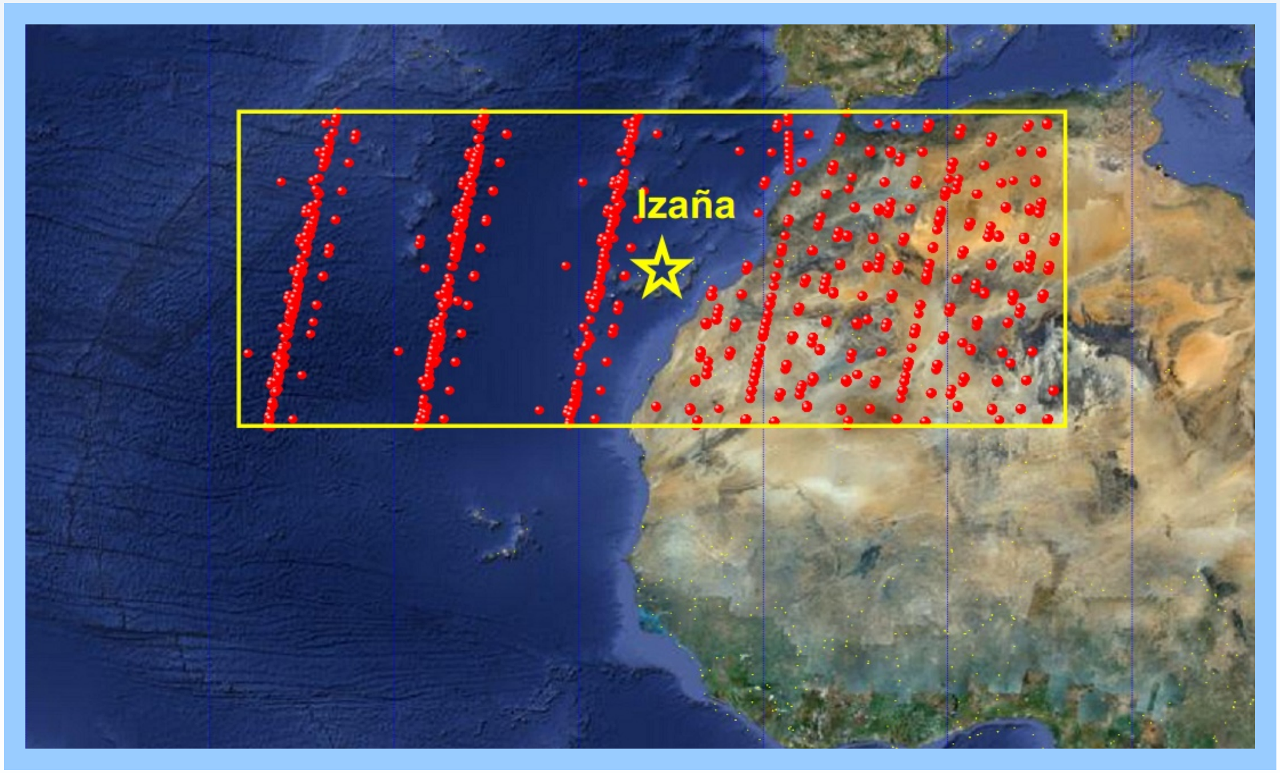
GOSAT-TCCON XCO_2 correlation diagrams for all five algorithms

Generally, GOSAT XCO_2 PPDF-S retrievals ↓ look well

At least, it provided the lowest bias and standard deviation ↓ as compared with TCCON data



Seasonal trends of GOSAT retrievals around Izaña site

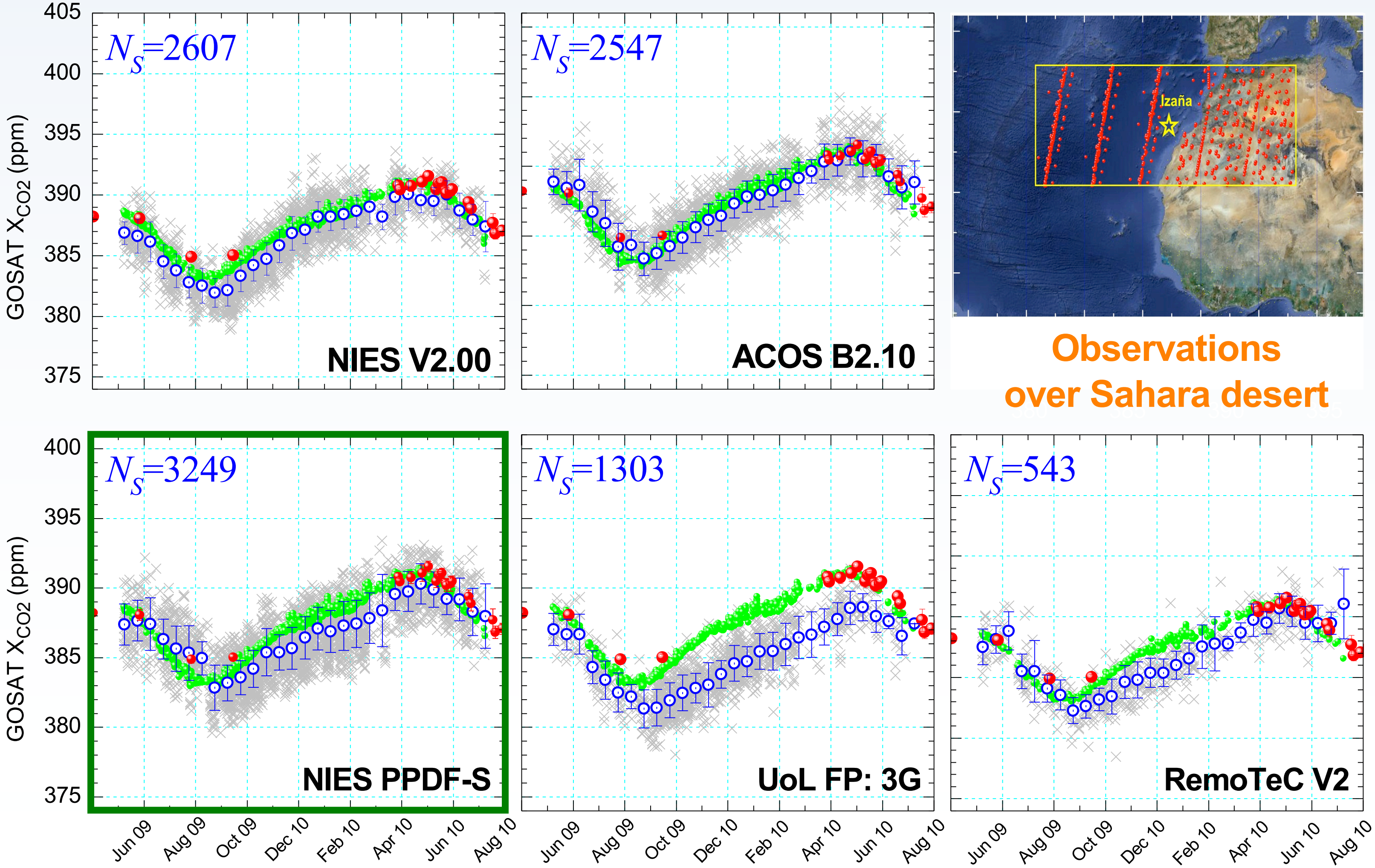


This site has an unique location for providing validation of satellite-based measurements. Here we could expect strong dust aerosol both over dark (ocean) and bright (Western part of Sahara desert) surfaces.

Seasonal trend of XCO_2 for five algorithms over Sahara desert ↓

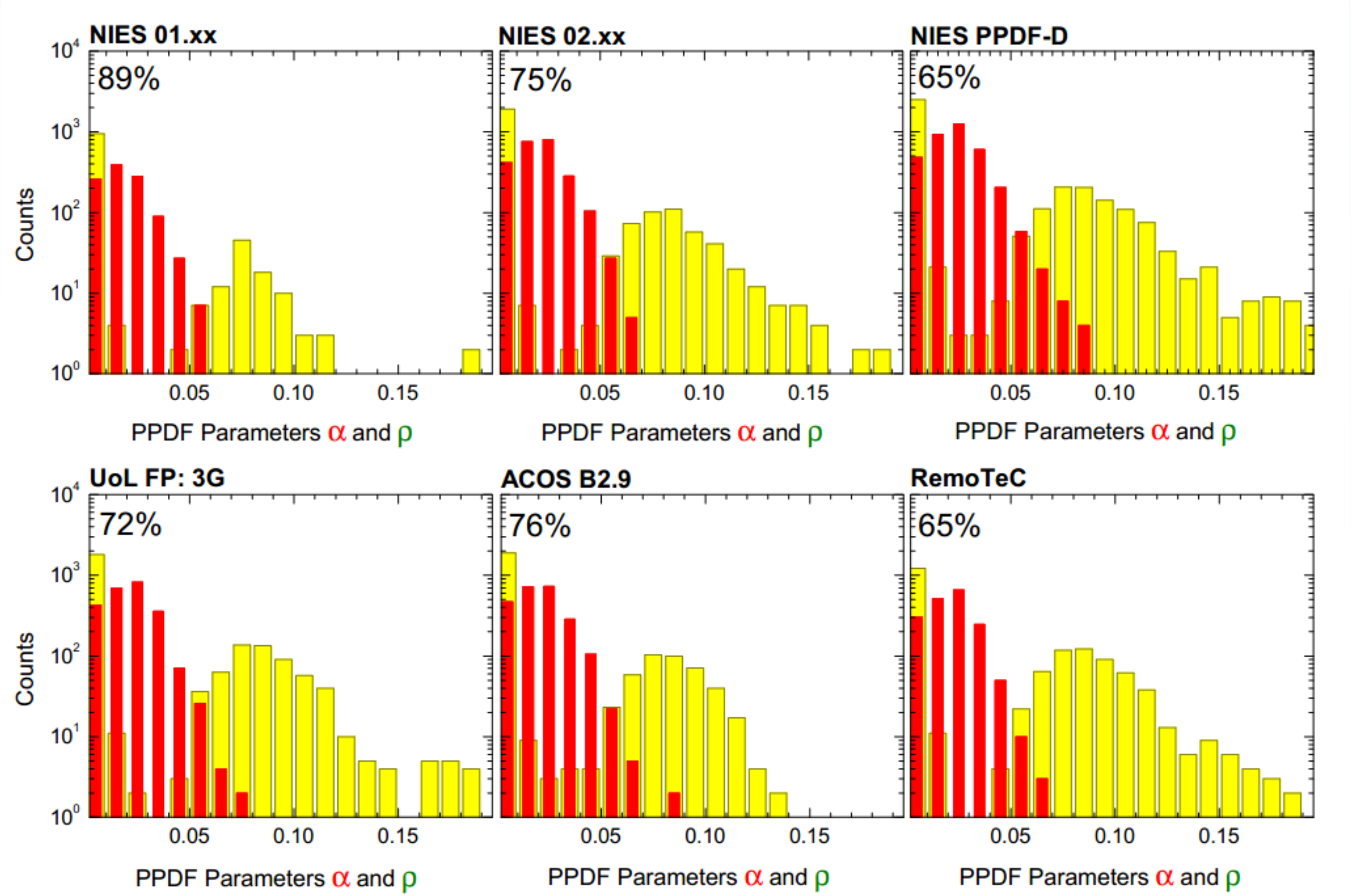
The retrievals - blue colors, red - FTS measurements, green ATM

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



GOSAT single scan counters distributed by PPDF parameters from different algorisms

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

1. Bril A., S. Oshchepkov, T. Yokota, and G. Inoue (2007), Parameterization of aerosol and cirrus cloud effects … ***Applied Optics***, 2007, *46*, 13, P.2460-2470.
2. Oshchepkov, S., A. Bril, and T. Yokota (2008), PPDF- D method …, ***JGR,*** *113*, D23210, doi:10.1029/2008JD010061.
3. Bril, A., S. Oshchepkov, T. Yokota (2008), …. model study of desert dust aerosol, ***JQRST***, *109*, 1815-1827.
4. Bril A., S. Oshchepkov, and T. Yokota (2009), Retrieval of atmospheric methane …, ***Applied Optics***, Vol. 48, No. 11. P. 2139-2148.
5. Oshchepkov S., A. Bril, and T. Yokota (2009), An improved … model … ***JGR***. *114*, D19207, doi:10.1029/2009JD012116.
6. Oshchepkov S., A. Bril,S. Maksyutov, and Tm Yokota (2011) Detection of optical path in spectroscopic space-based observations of greenhouse gases: Application to GOSAT data processing, ***JGR***, 116, D14304, doi:10.1029/2010JD015352.
7. Bril A., S. Oshchepkov, and T. Yokota (2012), Application of a probability density function-based atmospheric light-scattering correction to carbon dioxide retrievals from GOSAT over-sea observations, ***Remote Sensing of Environment***, *117C*, 301–306.
8. Oshchepkov, S., A. Bril, T. Yokota, et al. (2012), … validation … PPDF-D … retrievals …, ***JGR***, *117*, D12305, doi:10.1029/2012JD017505.
9. Oshchepkov, S., A. Bril, T. Yokota, et al. (2013), … Part 2: Algorithm intercomparison …, ***JGR***, 118, doi:10.1002/jgrd.50146.
10. Oshchepkov, S., A. Bril, T. Yokota, et al. (2013), Simultaneous retrieval of atmospheric CO2 and light path modification …, ***Applied Optics,*** Vol. 52, P. 1339-1350

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)