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Improvement of Yonsei CO_2 retrieval algorithm with modified aerosol information using GOSAT measurements

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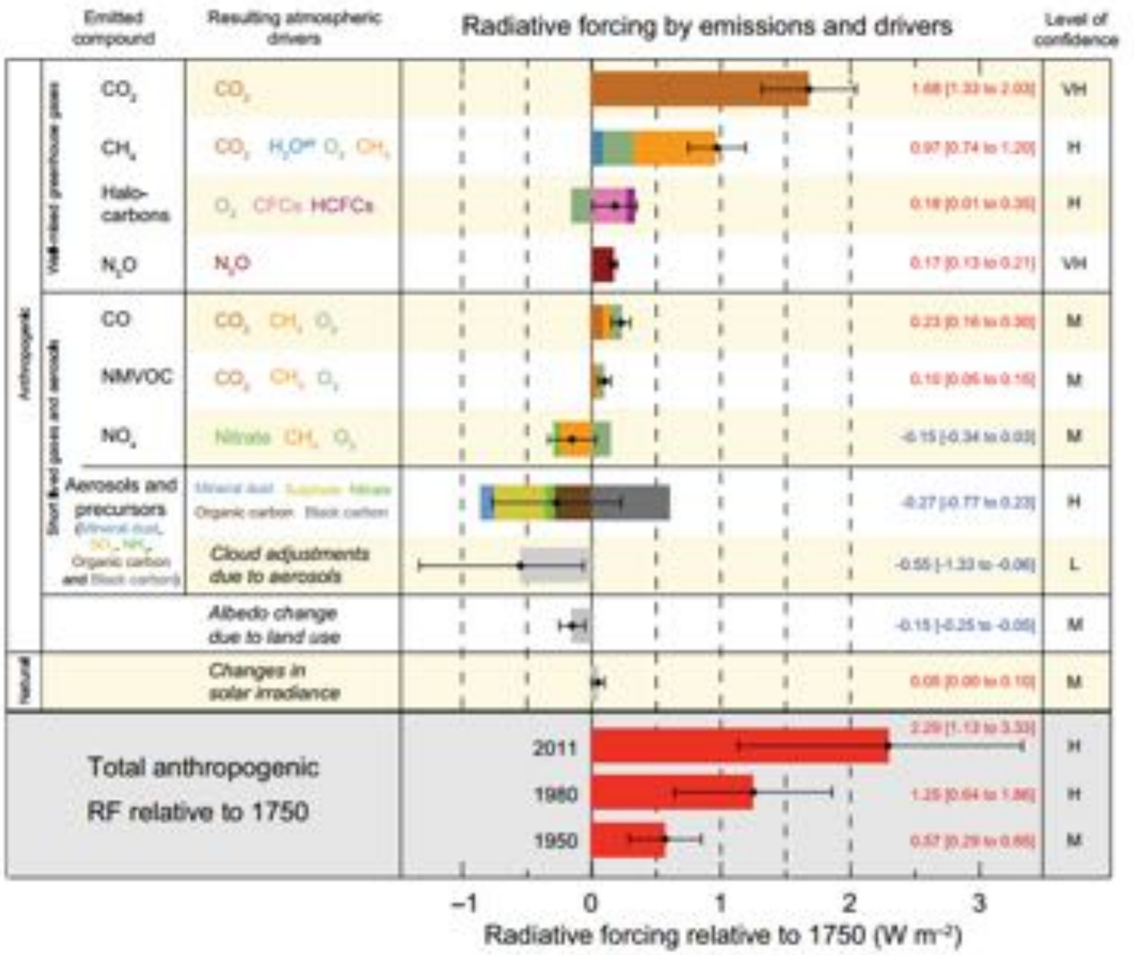
Carbon Dioxide (CO_2)



IPCC (2013)

- **Carbon dioxide (CO_2) is one of the long-lived anthropogenic greenhouse gases and has the largest radiative forcing on climate change. While much progress in knowledge of the global carbon cycle has been made, it is still required an adequate understanding of the system.**

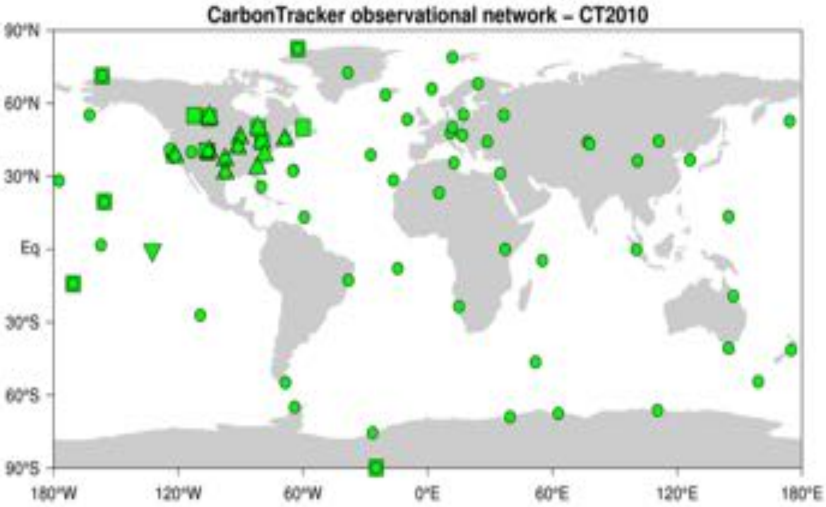
Estimation of carbon source and sinks

- The inverse modeling of atmospheric transport using in-situ measurements is required to estimate carbon sources and sinks (Rayner *et al.*, 1999). However, this approach is currently limited by the sparse distribution of the global flask sampling programs. Satellite remote sensing of CO_2 permits much higher density observations in space and time compared to current situation. It has the potential to reduce strongly the uncertainties of the atmospheric transport inversion (Rayner and O''Brien, 2001; Houweling *et al.*, 2004). It is worthwhile to explore the possibility of retrieving useful information from the satellites.

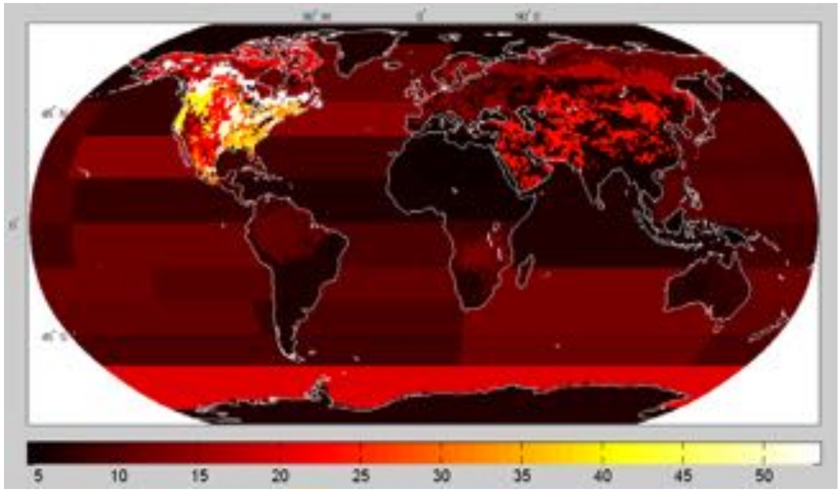
Uncertainty reduction

provided by inverse method

for the estimation of CO_2 fluxes (2000-2008)



~ 100 measurements a week



(Courtesy of C. Cho)

Objectives of this Study

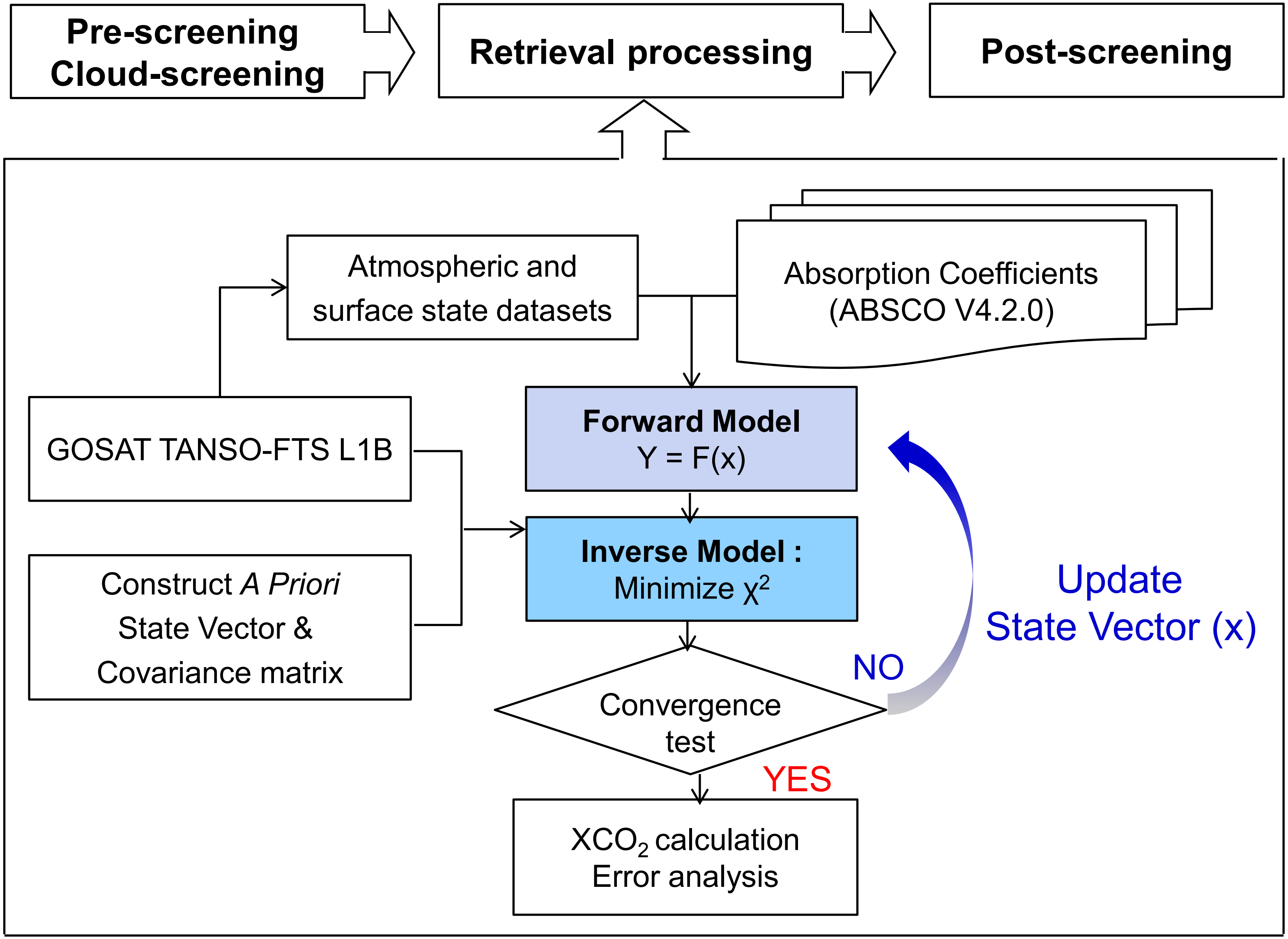
I. **The development of Yonsei CO_2 retrieval algorithm (YCAR) using SWIR bands of TANSO-FTS**

- Use optimized *A priori* datasets for CO_2 and Aerosols over East-Asia
- Estimate the retrieval errors caused by inaccurate aerosol information

II. **The improvements of Yonsei CO_2 retrieval algorithm (YCAR-A) with the modified aerosol parameters**

- Consider AOD profiles and AOP as state vectors in forward model
- Reduce the errors by inaccurate aerosol information
- Improve the accuracy of retrieval algorithm

The flow chart of the YCAR algorithm



Pre-screening
Cloud-screening

Retrieval processing

Post-screening

Atmospheric and surface state datasets

Absorption Coefficients (ABSCO V4.2.0)

GOSAT TANSO-FTS L1B

Forward Model
$Y = F(x)$

Construct *A Priori* State Vector & Covariance matrix

Inverse Model :
Minimize χ^2

Convergence test

NO

Update State Vector (x)

YES

XCO_2 calculation
Error analysis

State Vectors

- The “state structure” include atmospheric and surface properties that affect the spectrally dependent radiances observed by the satellites.

Names	Quantity	A Priori datasets	A priori value	A priori 1-σ	Description
CO_2	20 levels	CT-Asia	CT-Asia	Fixed	Volume Mixing Ratio at each level
H_2O	1	ECMWF	1.0	0.5	Multiplier to a priori profile
Temperature shift	1	ECMWF	0 K	5 K	Additive offset to a priori profile
Surface Pressure	1	ECMWF	ECMWF	4 hPa	Surface Pressure
Aerosols	19 layers (3 types)	MODIS CALIOP (AERONET)	0.05	Fixed	AOD profiles at each level for user-defined types
Surface Albedo	3 bands × 2 variables	Spectrum	Spectrum	1.0	Albedo at band centre
			0.0	0.0005/cm^{-1}	Albedo slope
Wavenumber calibration	3 bands × 2 variables	Spectrum	Spectrum	0.5 cm^{-1}	Wavenumber shift
			Spectrum	10^{-5} cm^{-1}	Wavenumber squeeze
Zero-level offset	1	-	0.0	10^{-8} $W/cm^{-2}/str/m^{-1}$	Radiance offset at band 1
Total	55				

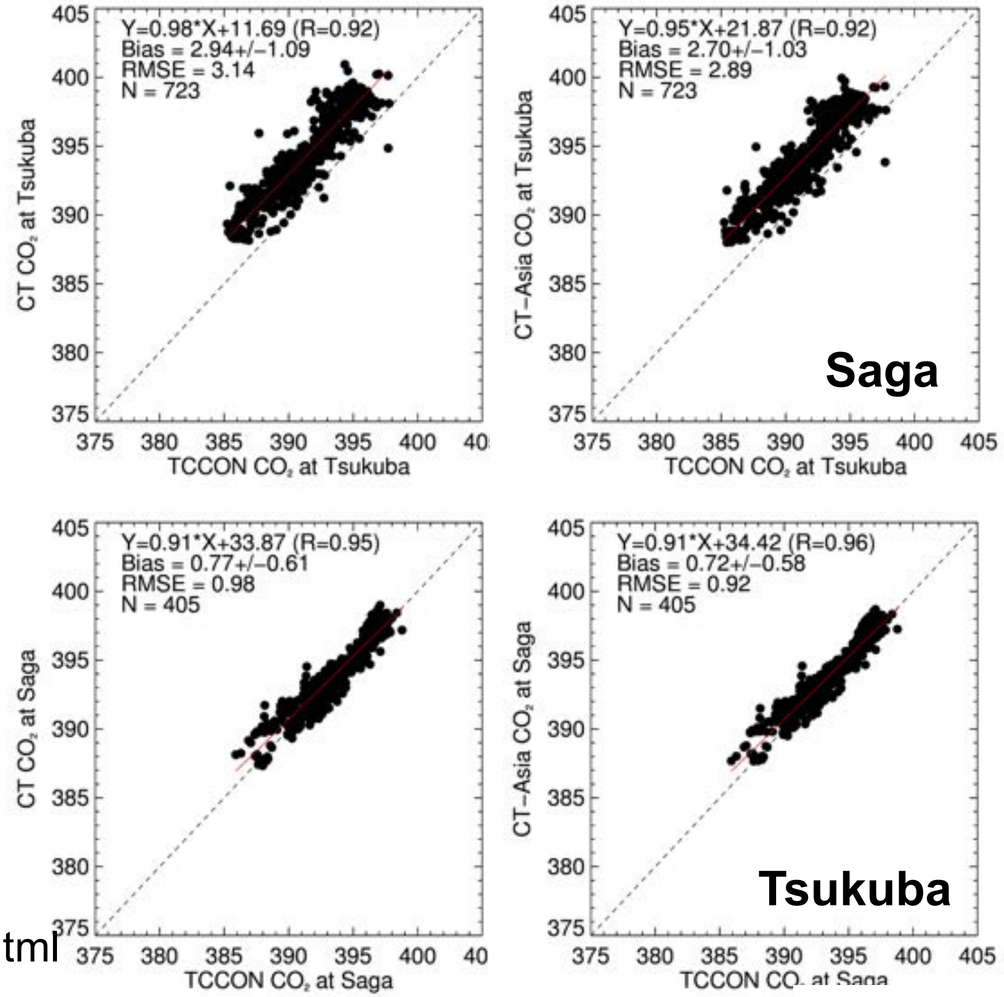
a priori of CO_2 Profiles: CarbonTracker-Asia

- The Carbon Tracker-Asia (CT-Asia), which was developed by the National Institute of Meteorological Sciences (NIMS), is based on the Carbon Tracker, these two models show some differences in terms of the transport resolution and the PBL scheme.
- CT-Asia used the JMA CO_2 observation datasets which were not assimilated in CT-NAM.
- the CO_2 mole fractions derived from the CT-Asia is slightly well correlated with ground-based FTS, as compared to those derived from the CT. It can be explained that optimized *a priori* of CO_2 mole fractions can reduce the CO_2 retrieval error.

CarbonTracker-Asia available at
http://www.nimr.go.kr/2/carbontracker/index.html

CarbonTracker

CarbonTtracker -Asia



Aerosol Models over East-Asia

- **AERONET Inversion datasets (Dubovik & King, 2000)**
  - **2001 -2010 over East-Asia (24-50N, 112-150E)**
  - **Volume/number size distribution**
  - **Refractive index**

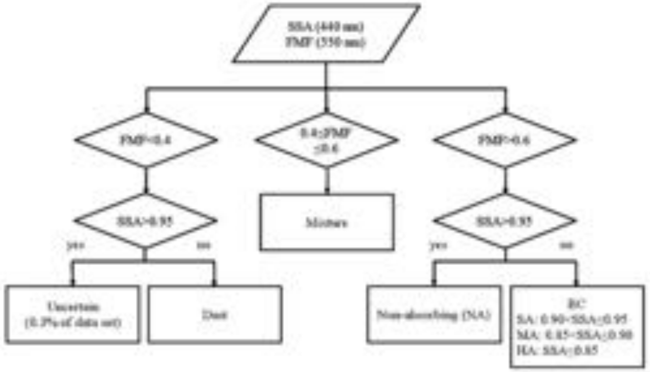
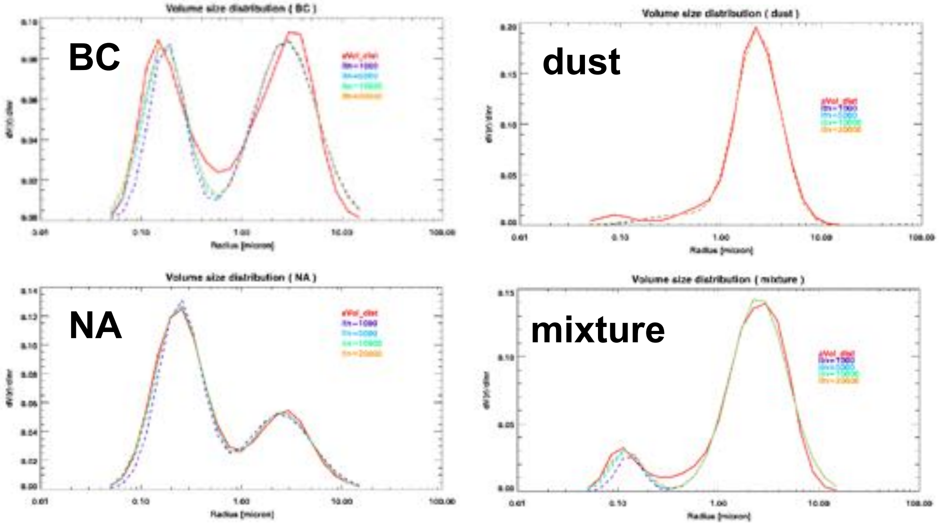


Fig. 1. Flowchart of the aerosol classification algorithm for AERONET. The HA, MA, SA, and NA represent highly-absorbing, moderately-absorbing, slightly-absorbing, and absorbing fine-mode aerosols, respectively.



Lee et al. (2010)

	r_{m1}	r_{m2}	σ_{m1}	σ_{m2}	FMF	ref_index (real)	ref_index (imaginery)
BC	0.0755	0.6421	1.6768	2.0082	0.9991	1.4862	0.00999
Dust	0.0409	1.1031	2.3704	1.6472	0.9948	1.5462	0.00199
NA	0.0881	0.6637	1.7767	1.9553	0.9993	1.4264	0.00404
MIX	0.0741	0.6955	1.4909	1.9254	0.9972	1.5313	0.0

Modification of aerosol parameters

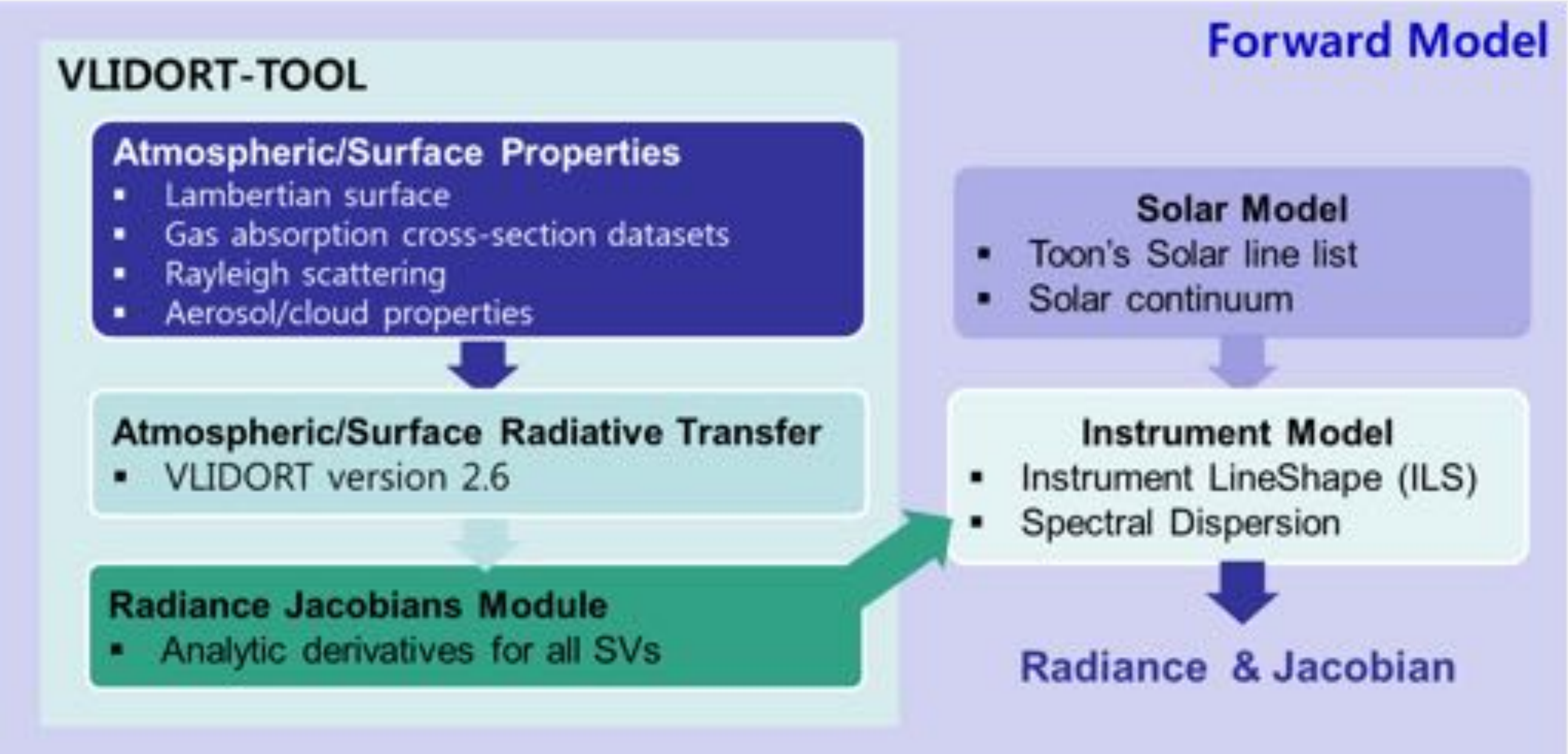
- Represent aerosol optical properties and reduce the errors
- Minimize the number of parameters to account for aerosols
- Exclude time-consuming radiative transfer calculations

Names	Quantity	A Priori datasets	A priori value	A priori 1-σ	Description
YCAR (N_{tot} = 55)	19 layers (3 types)	MODIS CALIOP (AERONET)	0.05	Fixed	AOD profiles on each level for user-defined types
YCAR - Aerosol (N_{tot} = 48)	1	-	MODIS	0.5 (F)	Total optical depth of aerosols
	1	-	2	3.0 (F)	Peak height parameter of aerosol vertical distribution
	1	-	0.1	2.0 (F)	Half width parameter of aerosol vertical distribution
	2	AERONET	Selected AOD type (BC, Dust, NA)	0.002835	Real refractive index for fine and coarse mode
	2			2.5729E-5	Imaginary refractive index for fine and coarse mode
	2			0.003278 0.2580	Log-normal Mode radius for fine and coarse mode
	2			0.077497 0.0913	Log-normal Standard deviation for fine and coarse mode
	1			0.001828	Bimodal fraction for particle size on

F (Frankenberg et al., 2012)

Forward Models

- The Forward Model can generate synthetic spectra and jacobians.
- The Forward Model needs to describes accurately physics of measurement.



Forward Model

VLIDORT-TOOL

Atmospheric/Surface Properties
- Lambertian surface
- Gas absorption cross-section datasets
- Rayleigh scattering
- Aerosol/cloud properties

Atmospheric/Surface Radiative Transfer
- VLIDORT version 2.6

Radiance Jacobians Module
- Analytic derivatives for all SVs

Solar Model
- Toon's Solar line list
- Solar continuum

Instrument Model
- Instrument LineShape (ILS)
- Spectral Dispersion

Radiance & Jacobian

Corrections to reduce the biases

I. Spectroscopic uncertainties

- Updated spectroscopy (ABSCO V4.2.0) (Vivienne, 2015)
- CO_2 and O_2 absorption coefficients, including line-mixing and collision-induced absorption.
- O_2 cross-section Scaling factor : 1.0125
- CO_2 cross-section Scaling factor : 0.9946 at SCO_2 band, 1.0038 at WCO_2 band

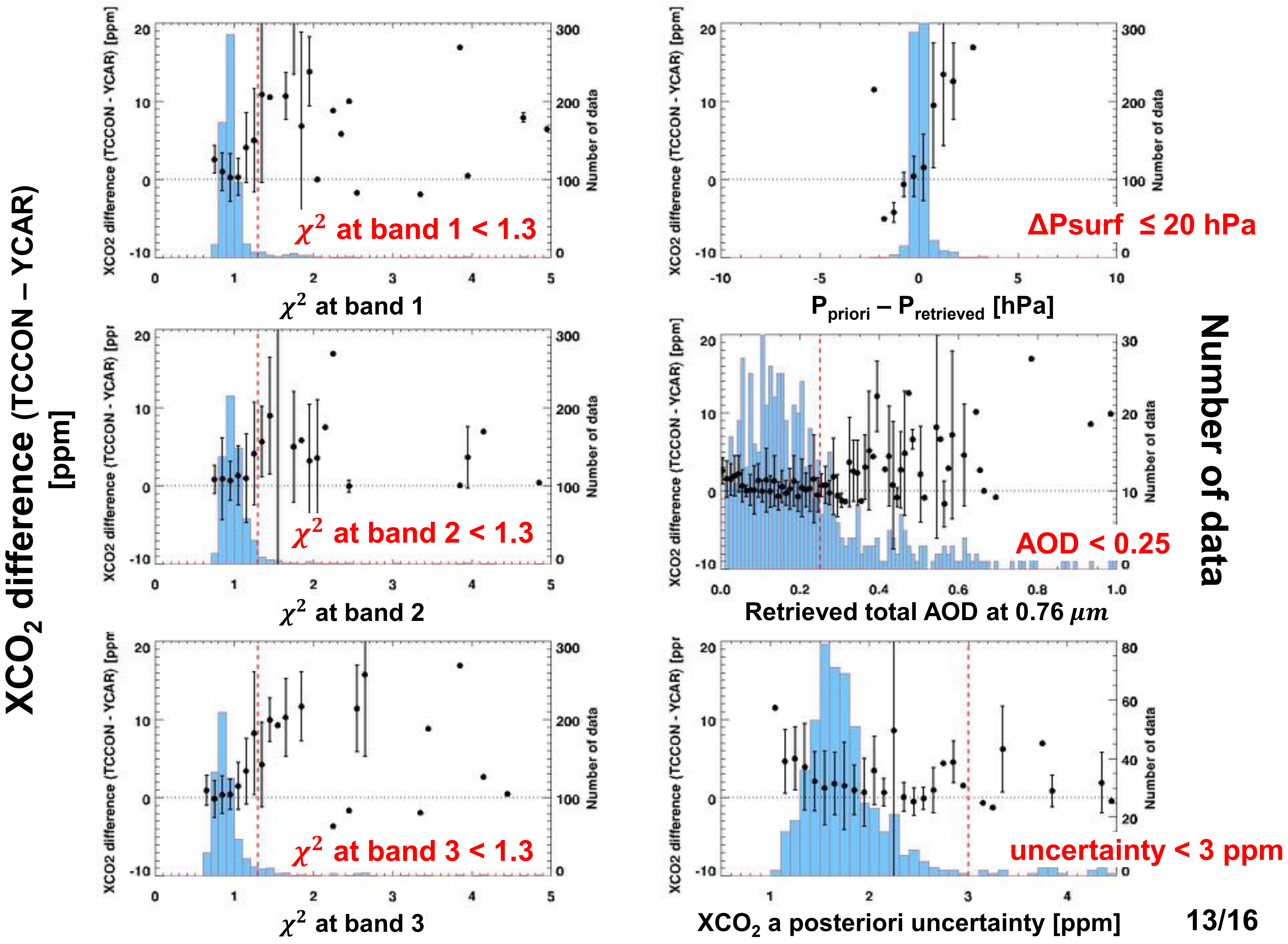
II. Non-linear response of TANSO-FTS at O_2-A band

- Non-linear response of the detector recording the interferogram creates a radiance offset.
- It could be reduced by including a wavenumber-independent offset for O_2 A-band radiance, referred to as zero-level offset (zLo).

III. Empirical noise

- to consider model parameters and forward model error using Yoshida et al. (2013)
- Neglecting the contribution of forward model error and model parameter error, χ^2 (the retrieved state) increase as the signal-to-noise ratio (SNR) increased, indicating that the contribution of forward model error and model parameter error became large with SNR.

Post-screening Processing



Validation with g-b FTS

± 1 hour GOSAT overpass time
± 2 degree latitude/longitude box centered at each TCCON site

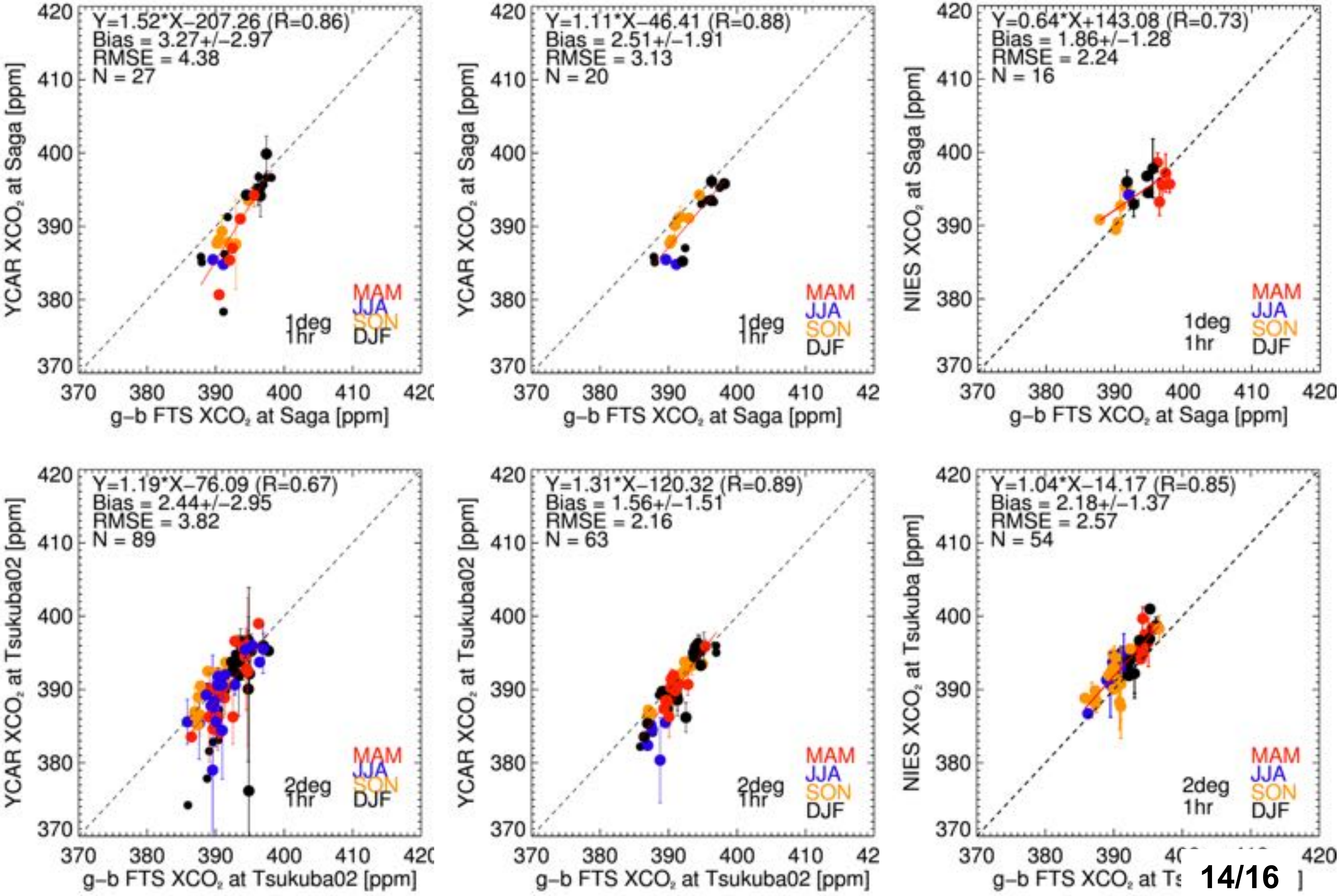
YCAR (pre-screen)

YCAR (post-screen)

NIES V2

Saga

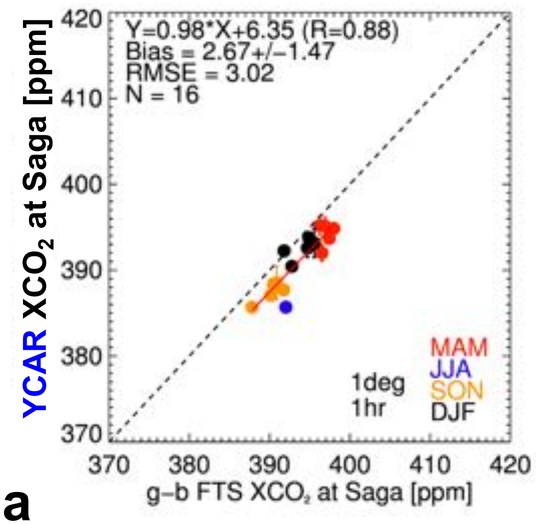
Tsukuba

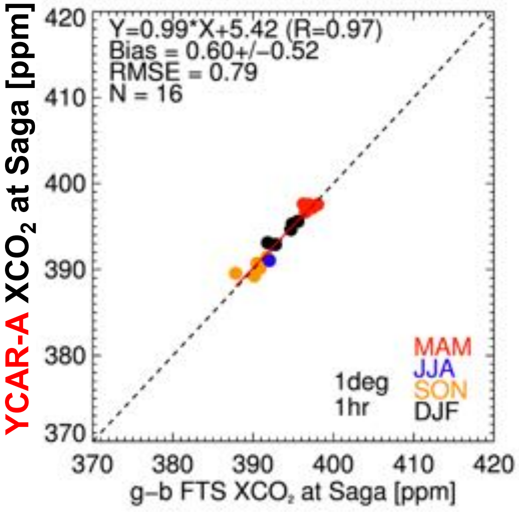


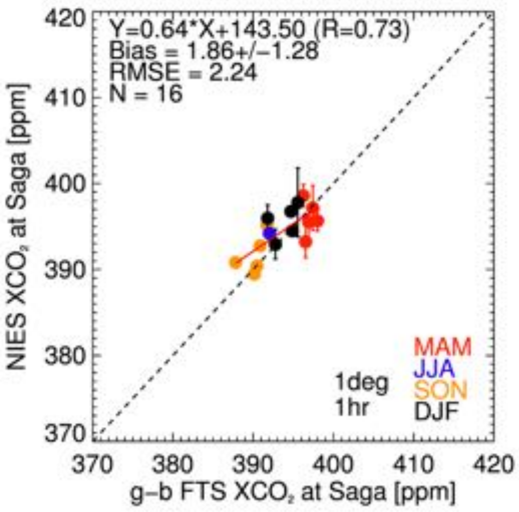
Validation with g-b FTS

YCAR | **YCAR – A** | **NIES V2**

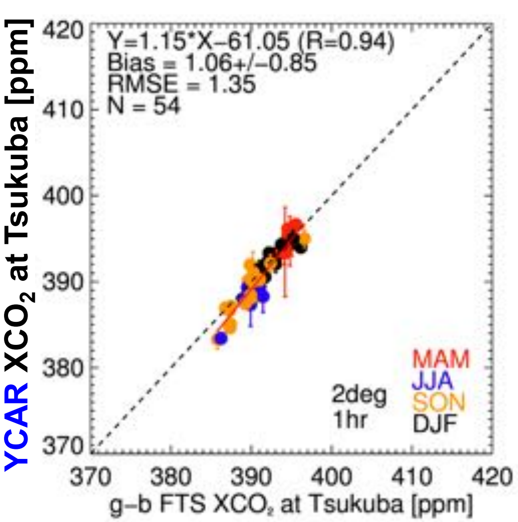
Saga

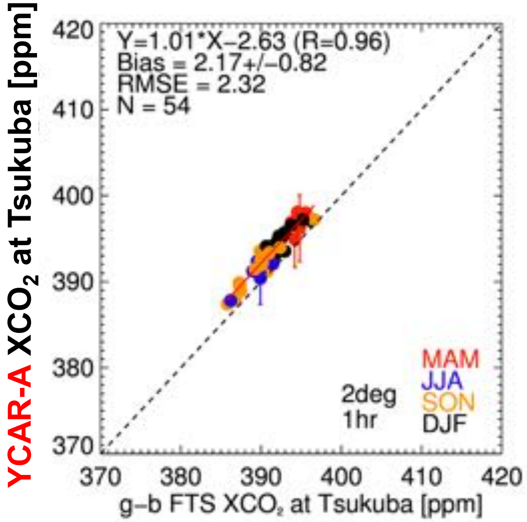


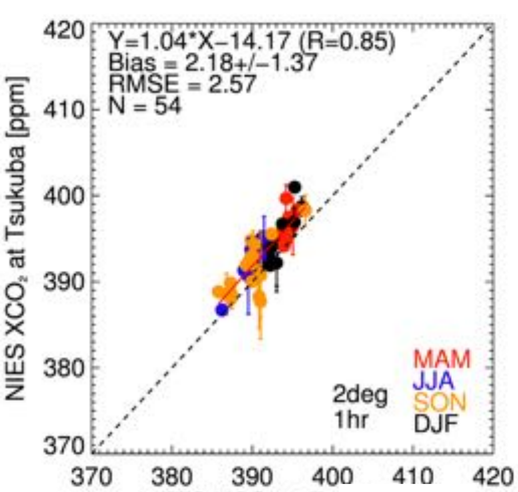




Tsukuba







Summary and Future Works

- Based on an optimal estimation method, an algorithm was developed to retrieve the column-averaged dry-air mole fraction of carbon dioxide (XCO_2) using shortwave infrared (SWIR) channels. The retrieval results are biased by 2.51±1.91 ppm (R=0.88) and 1.56±2.17 ppm (R=0.89) at Saga and Tsukuba, respectively. It is competitive results with more retrieval data and higher correlation coefficients than GOSAT standard products (0.73 and 0.85 at Saga and Tsukuba, respectively).

- The YCAR-A algorithm improved with the consideration of aerosol vertical distribution and its optical properties as state vectors in the forward model. The improved YCAR-A algorithm has reduced elements of state vectors that can decrease in solving the matrix in the inverse model as well as raised computational efficiency.

- Compared to previous results from YCAR algorithm, the improved YCAR algorithm has lower biases and higher correlation coefficients as well as in comparison with GOSAT standard products. The retrieval results are biased by 0.60±0.52 ppm (R=0.97) and 2.20±0.83 ppm (R=0.96) at Saga and Tsukuba, respectively.

- In the future, more validation will be examined at many TCCON sites. In addition, each error components will be examined and the most important forward model parameters can be analyzed through error analysis to improve the retrieval efficiency.

- The improvement of CO_2 concentration and aerosol with the aid of Carbon Tracker-Asia leads to more accurate evaluation of radiative forcing eventually.

See also Poster. 16. (June 9, Thu., 10:30-12:00)

“CO_2 Retrieval over East Asia using CAI aerosol information”
Woogyung Kim, et al. (Yonsei U., Korea)

Thank you for your attention!