Estimation of anthropogenic GHG emission rate for different sources in Japanese megacity by using airborne imaging-spectrometer suites

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Abstract

In almost Japanese megacities, various CO2 and CH4 emission source like industrial activity (power plant, landfills, gas factory, water processing plants), and agricultural activity (rice cultivation, pig farm) are concentrated within a few tens kilometers region. In order to estimate CO2 and CH4 emission rate for above various different sources, we newly developed airborne Imaging-spectrometer suites which consist of NIR spectrometer for O2-A band measurement and SWIR spectrometer for CO2/CH4 measurement. We also developed quick algorithm based on nonlinear fitting of synthetic spectrum to observation spectrum by optimization of column density of CO2 / CH4 and instrumental characteristic parameter simultaneously. The algorithm takes less than 20 second per 1 retrieval by using laptop computer, and we will challenge further acceleration by more than tens of times in order to realize real-time observation. For the first flight, we selected the eastern part of the Nagoya urban area, in which there are large CO2 emission sources, including a coal power plant and the transportation sector, and possible CH4 sources from agriculture, energy manufacturing, and waste that are geographically mixed. The results of observing the Hekinan power plant (coal-fired power generation) over Aichi Prefecture on Feb. 16, 2018 are shown in Figure 1. At the Hekinan Power Station, enhancement of CO2 column-averaged mole fractions are observed, and it can be seen that the high concentration area extends toward the downwind side. The accuracy of column density calculated by the quick algorithm will be validated with ground observation data. We estimated emission rate of CO2 of Hekinan Power plant.

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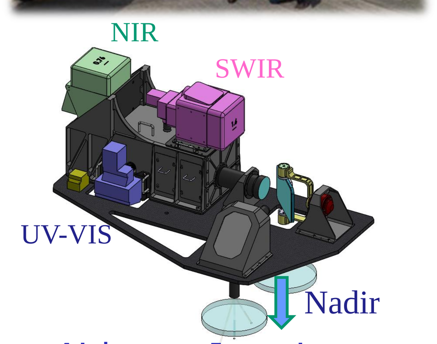
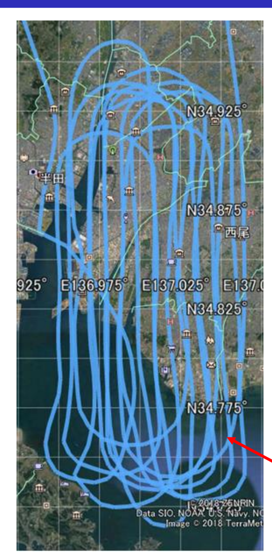
Motivation

In almost Japanese megacities, various GHG emission source like industrial activity (power plant, landfills, gas factory, water processing plants), and agricultural activity (rice cultivation, pig farm) are concentrated within a few tens kilometers region. In order to estimate GHG emission rate for above various different sources in the medium scale region, airborne remote sensing approach is one of the best methodology with respect to its uniformity and extensiveness compared to in-situ measurement on the ground or by airplane, as well as to its high spatial resolution and sampling frequency compared to space-borne remote sensing.

Flight Experiment



Airborne Imaging-spectrometer suites (Courtesy of Kurose)



Flight route On Feb. 16,2018

For the first flight, we selected the eastern part of the Nagoya urban area, in which there are large CO_2 emission sources, including a coal power plant and the transportation sector, and possible CH_4 sources from agriculture, energy manufacturing, and waste that are geographically mixed.

Photo of the coal fired power plant located in greater Nagoya, taken from the airplane on Feb.16.2018

Instrumental specification

Target spices	NO_2	O_2 A and SIF	CO_2 and CH_4
Spectral coverage	250-600 nm (UV-VIS)	747–783 nm (NIR)	1560–1670 nm (SWIR)
Spectral resolution	1.45nm	0.09 nm	0.17nm
GSD (at 2.9km height)	~50m (after 50 pixel binning)	~50m(after 64 pixel binning)	~40m (after 16 pixel binning)
Swath (at 2.9km height)	~1.1km	~1.6km	~1.3km
Integration time	0.5 sec (typical)	0.5 sec (typical)	0.5 sec (typical)

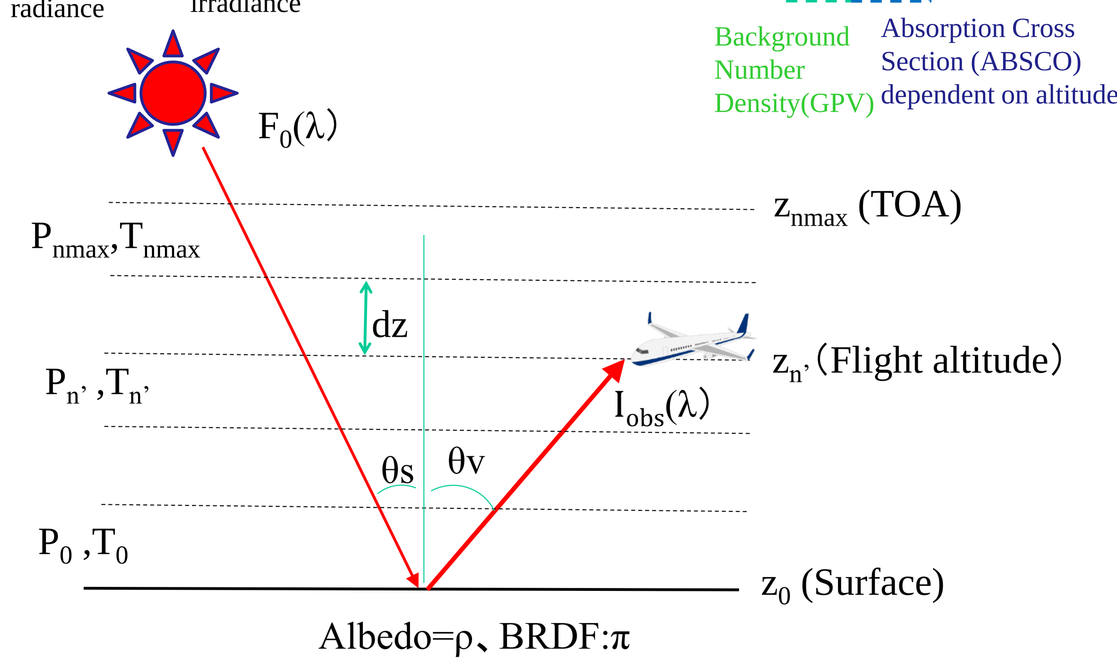
CO_2 retrieval algorithm

The purpose is to obtain CO_2 column averaged mole fractions(XCO_2) quickly and accurately while correcting the characteristics of the instrument. The basic idea is to fit a simulation spectrum with XCO_2 as a variable to the observed spectrum. In order to increase the agreement between the two, processing before fitting is important. The simulation spectrum is obtained by inputting the solar irradiance spectrum (Toon Fraunhofer line and NIES continuum) into a forward model based on the Lambert-Bear method that does not consider scattering. The background atmosphere in the forward model was divided into 143 layers, and the CO_2 absorption cross section was taken into the forward model from ABSCO v4.2 in consideration of the atmospheric pressure and temperature of each layer obtained by the GPV analysis on the day. Geometry such as solar zenith angle and viewing zenith angle was calculated based on the sun position calculation tool and GNSS/IMU mounted on the airplane on the day of flight. On the other hand, for the observed spectrum, wavelength calibration and radiometric calibration were performed according to prior ground test data. In the nonlinear fitting process, in addition to XCO_2, instrumental characteristics such as wavelength position, ILS width, spectral intensity and its slope were also taken as fitting parameters. XCO_2 was assumed to be constant in the altitude direction.

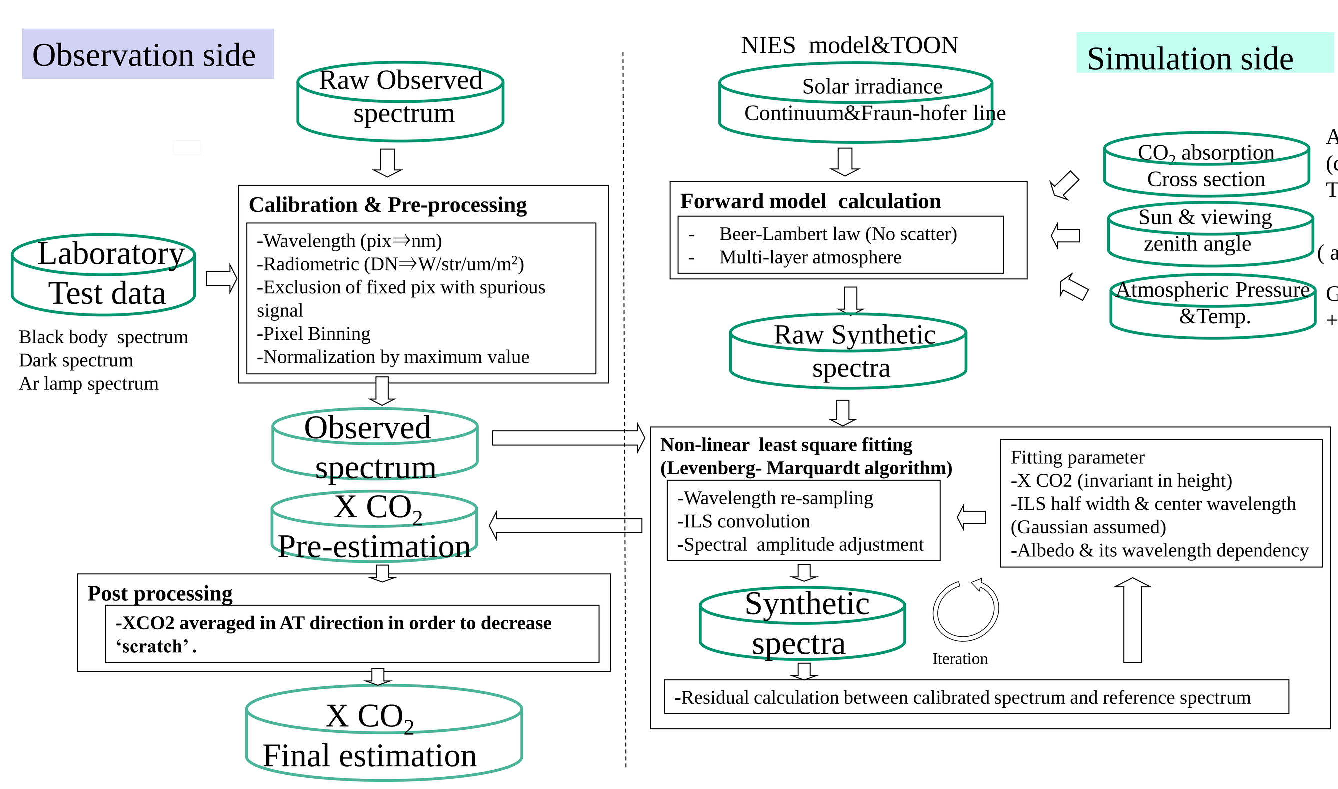
Simple forward-model based on Lambert-Beer Law

$$I_{obs}(\lambda) \fallingdotseq F_0(\lambda)\cdot\frac{\rho}{\pi}\cdot exp\left[-X_{CO2}\left(\frac{1}{\cos\theta s}\int_{z0}^{z_{nmax}} n_{dry}\,\sigma_z(\lambda)\,dz+\frac{1}{\cos\theta v}\int_{z0}^{z_{n'}} n_{dry}\,\sigma_z(\lambda)\,dz\right)\right]$$

Observed radiance; Solar irradiance; Target; Background Number Density(GPV); Absorption Cross Section (ABSCO) dependent on altitude



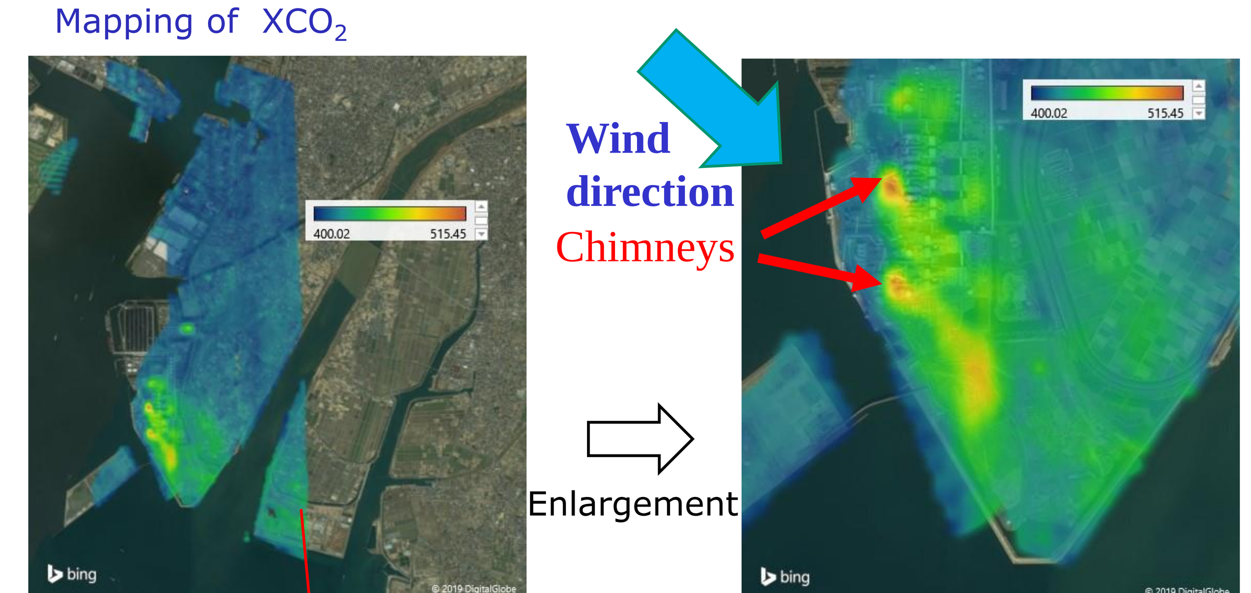
Overall structure of the GHG retrieval program

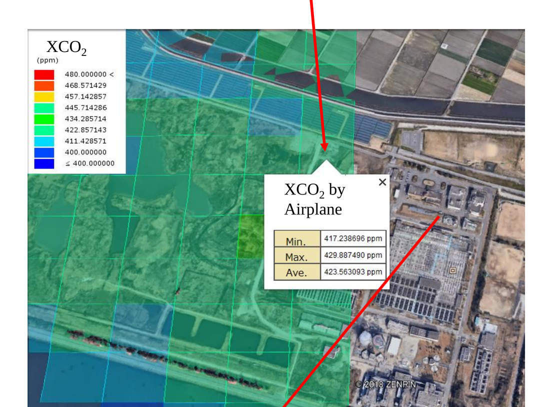


Results

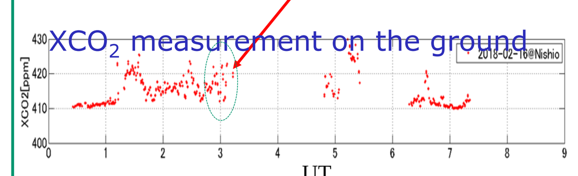
The observation results of CO_2 and NO_2 for the February 16, 2018 flight are shown below. In CO_2 observation, significant enhancement was found above the chimney of a coal-fired power plant. The results of the CO_2 retrieval analysis are also shown. The simulation spectrum and the observed spectrum were in agreement with a residual of +/- 1% at almost wavelengths, and the XCO_2 was very high at 490ppm. In addition, northwesterly winds were blowing on the day, confirming that a high concentration range flows as a plume on the leeward side. Furthermore, the ground observation result by CO_2 using EM27 at the same time as the flight is shown. During flight observation time (UT2), enhancement was also confirmed by ground observation. XCO_2 was also in good agreement with airborne observations of about 423 ppm, while ground observations were about 420 ppm.

Mapping of XCO_2

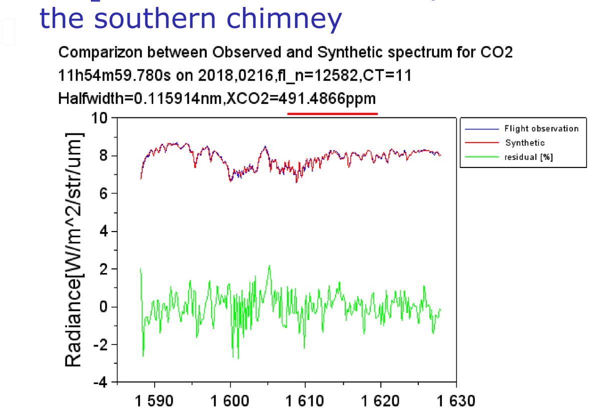




XCO_2 measurement on the ground

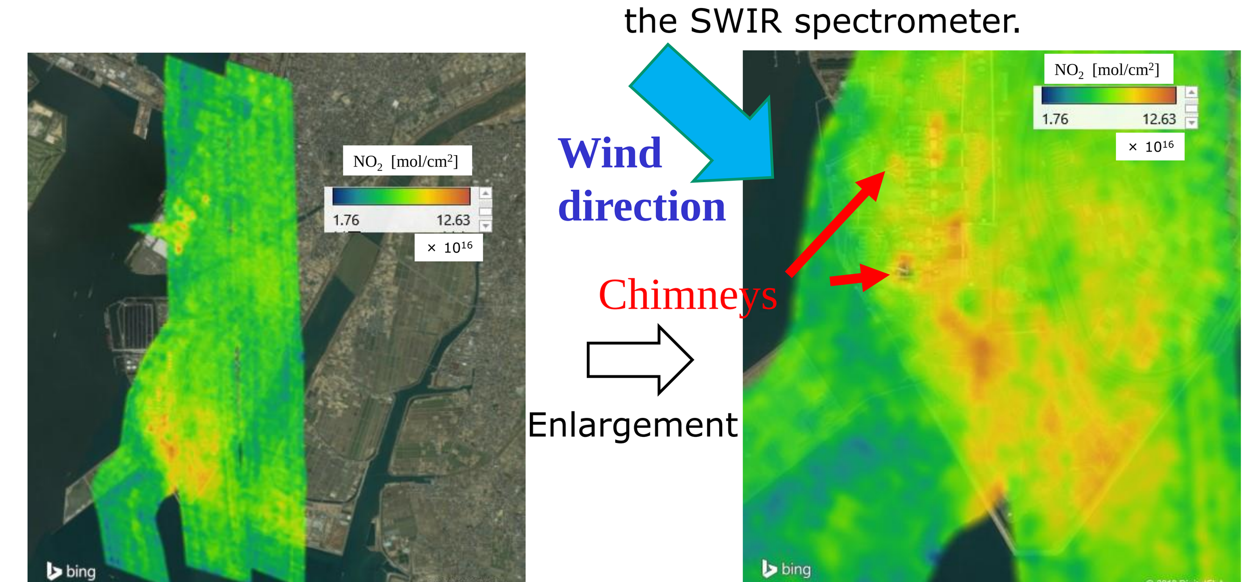


XCO_2 Retrieval results exactly above the southern chimney



NO_2 observations also confirmed enhancements above the chimney. However, it was not as prominent as CO_2. This is because the SNR of the UV-VIS spectrometer was lower than that of the SWIR spectrometer.

Mapping of column amount of NO_2



Discussion

We tried to roughly estimate emission rate of CO_2 (Q)from the power plant based on the airplane observation result.

$Q=\Delta\rho_{plm}\cdot V_{ver}\cdot S$

V_{ver} : Upward velocity of the plume (un-known, but 5 [m/s] is assumed)

S is cross sectional area of density flux [m^2] estimated as follows

$\pi\cdot(\sigma_h/2)^2$

σ_h : Horizontal plume extension [m] (Estimated by flight observation)

$\Delta\rho_{plm}$ is CO_2 density enhancement in the plume from background [kg/m3] estimated as follows

$\Delta\rho_{plm} = \Delta\rho_{col} \times SH / \sigma_z$

SH: scale height ~ 8km

σ_z : Vertical plume extension [m] :assumed to be the same as σ_y

$\Delta\rho_{col}$ is CO_2 Column density enhancement in the plume from background estimated as follows

$\Delta\rho_{col} = \Delta XCO_2 \times \rho_{dry}$

ρ_{dry} : density of dry air = 1.293 [kg/m^3] (@1atm)

ΔXCO_2 =Enhancement of XCO_2 (Estimated by flight observation)

Substituted observation results of $XCO_2 \fallingdotseq 90$ppm and $\sigma_h \fallingdotseq 220$m (See below figure) resulted in CO_2 emission rate (Q) of 2.5×10^6 [kg/h]. There were 2 chimneys, then Q was multiplied by 2, then we finally estimated of CO_2 emission rate as $Q_{total} = 5.0 \times 10^6$ [kg/h] ----- ①

Verification of above accounts by using power generation information.

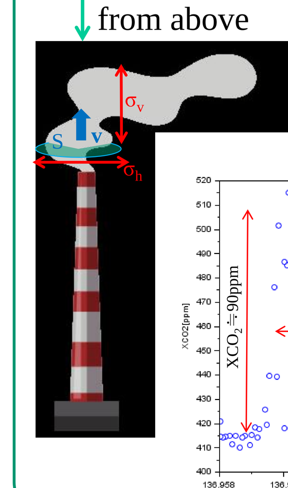
Power generation of the plant : $PG=4.1\times10^6$ [kW]

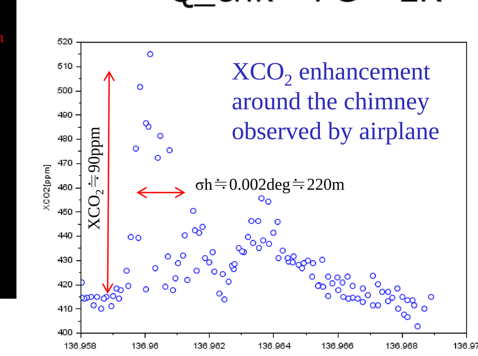
Specific Carbon Dioxide Emissions for Hard Coal: ER=0.34 [kg/h/kW]

(https://www.volker-quaschning.de/datserv/CO2-spez/index_e.php)

$Q\_chk = PG \times ER = 1.39\times10^6 [kg/h]$ ------------- ②

Observation from above



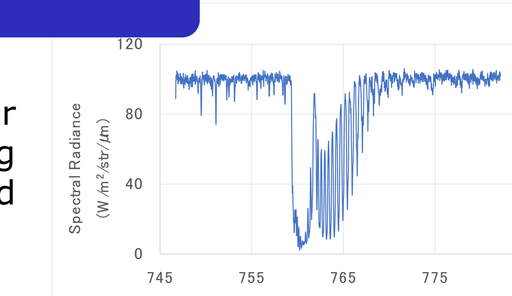


Degree of CO_2 emission rate estimated from observation(①) agreed with that from power generation information(②), but there was still large discrepancy. The largest error factors were σ_z and V_{ver} , because there was no direct measurement during the observation.

Future Work

More accuracy

Development of retrieval algorithm for optical depth determination in taking account for airmass factor determined by O2-A spectrum.



Faster algorithm

Currently, it takes 30 seconds to retrieve one observation point, so the cycle of feeding back XCO2 mapping results to algorithm development is slow. Optimize by trade-off between XCO2 derivation accuracy and calculation speed..

Detailed analysis

Improvement of data analysis methodology will realize detailed identification of emission source location. Combined with wind profile model (e.g. WRF) and solving the equation of continuity, emission rate will be determined in more detail.