A feasibility study for SO_2 detection from space

- part of study for GMAP-Asia -

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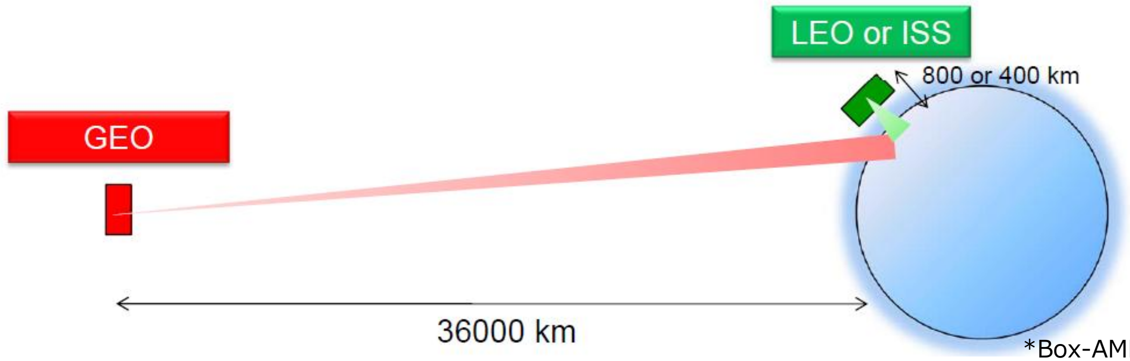
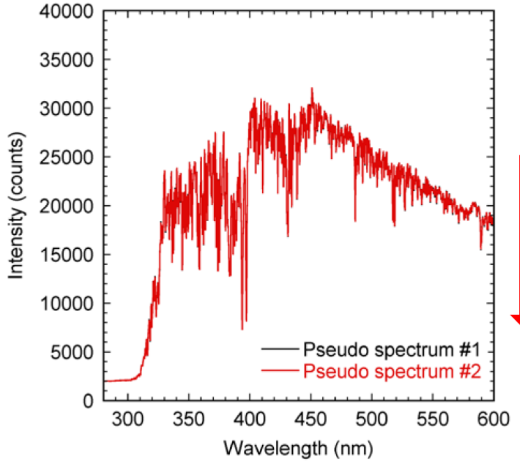
Overview of our feasibility study



*Box-AMF: AMF with respect to a layer

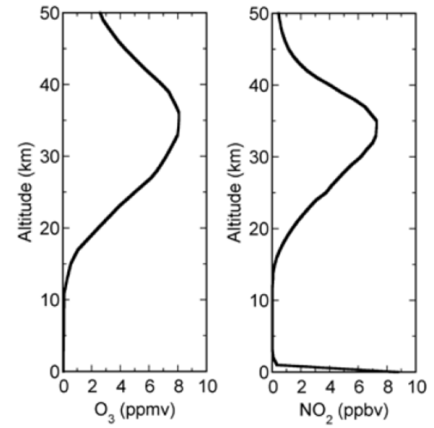


Radiance spectrum measured by a geostationary satellite sensor

Simulation by a radiative transfer model

Add noises according to sensor performance

Retrieval of column/concentration using DOAS method



Concentration/column of ozone and NO_2 in the Earth's atmosphere

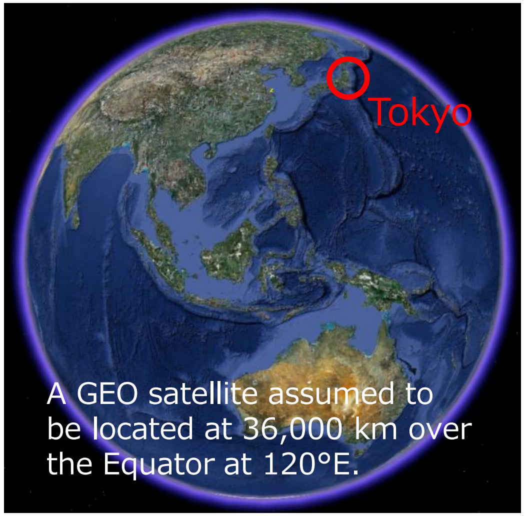
Sensor performance (signal-to-noise ratio, etc.) ⟷ Error in retrievals of column/concentration

This relationship to be evaluated

Simulation by a RTM

We use our RTM, **JACOSPAR**, which was developed based on its predecessor **MCARaTS** (Iwabuchi, 2006). MCARaTS was validated by an international RTM intercomparison study for **MAX-DOAS** geometries (Wagner et al., 2007).

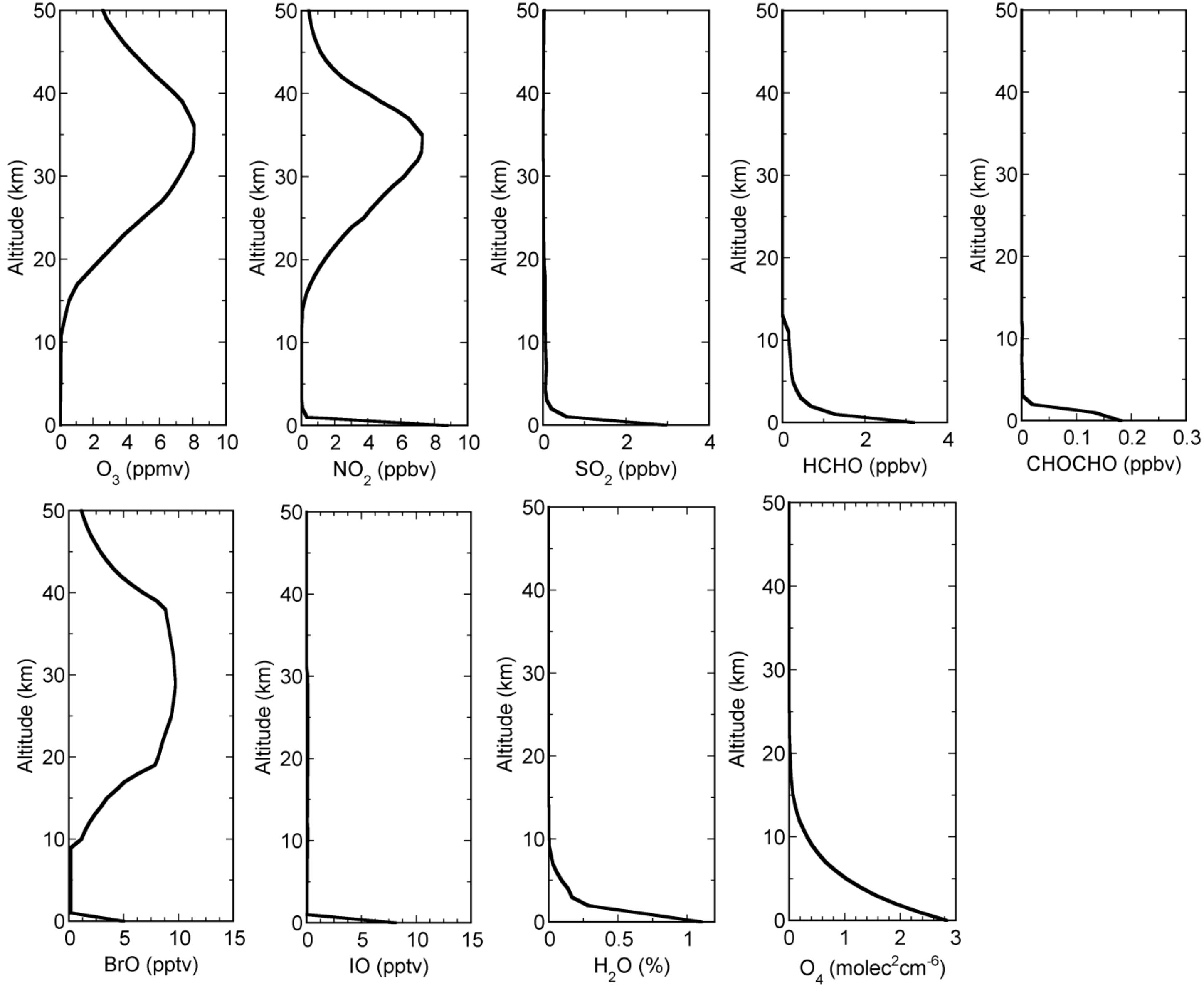
Observation of the atmosphere over Tokyo (35.7ºN, 139.7ºE).



Four geometries covering summer/winter and 12:00/15:00 local times.

Geometry #	Date	Local time (hour)	SZA (deg)	Azimuth (deg)
0	June 20 (Summer)	12	12.3	178.8
1		15	40.4	264.9
2	Dec. 20 (Winter)	12	59.1	180.7
3		15	73.2	223.3

Assumed profiles of trace gases



Creating synthetic spectra from simulated radiances

Radiance calculation by JACOSPAR		
Developed by Dr. Iwabuchi	Fast calc.	Validated

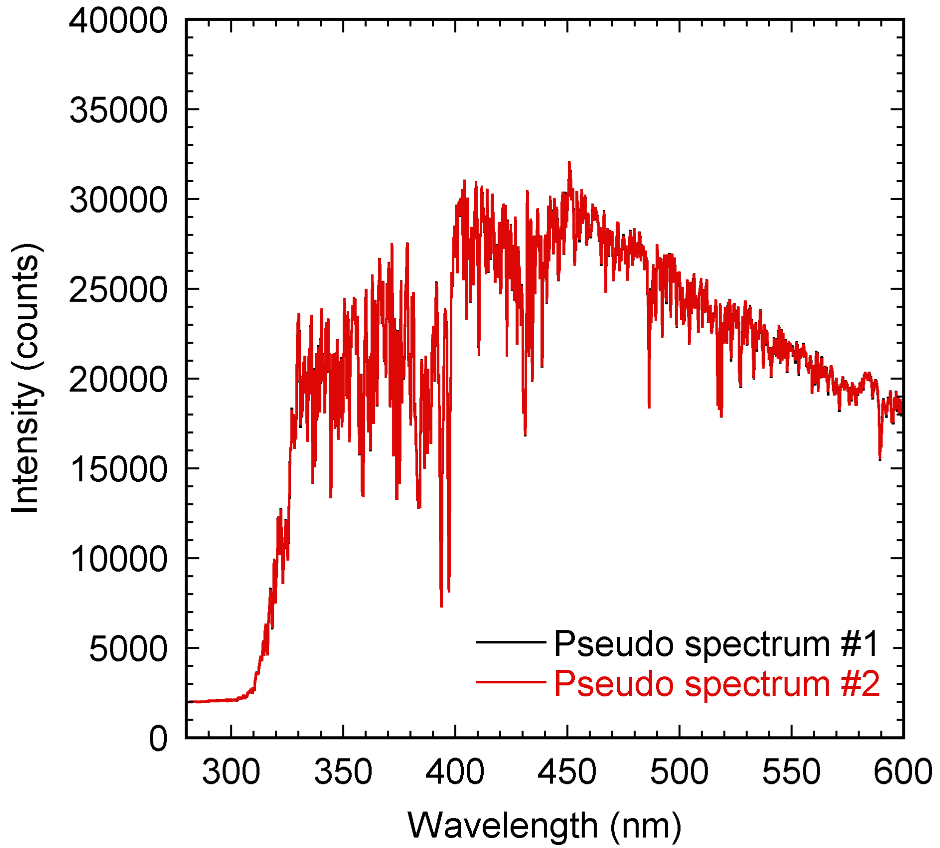
Scaling to a range 0-30,000 counts

Add offsets and noises

Convolved with slit function assuming FWHM, shift, sampling step

Create a synthetic spectrum

for each 0.01 nm



DOAS analysis

- Levenberg-Marquardt method: $\mathbf{x}_{i+1} = \mathbf{x}_i + (\mathbf{K}_i^T \mathbf{S} \mathbf{K}_i + \gamma_i \mathbf{D})^{-1} \mathbf{K}_i^T \mathbf{S} [\mathbf{y} - \mathbf{F}(\mathbf{x}_i)]$
- Forward model: $\ln I(\lambda) = \ln(I_0(\lambda) - c(\lambda)) - \sum_{i=1}^{n} \sigma_i(\lambda) \Delta \mathrm{SCD}_\mathrm{i} - p(\lambda)$

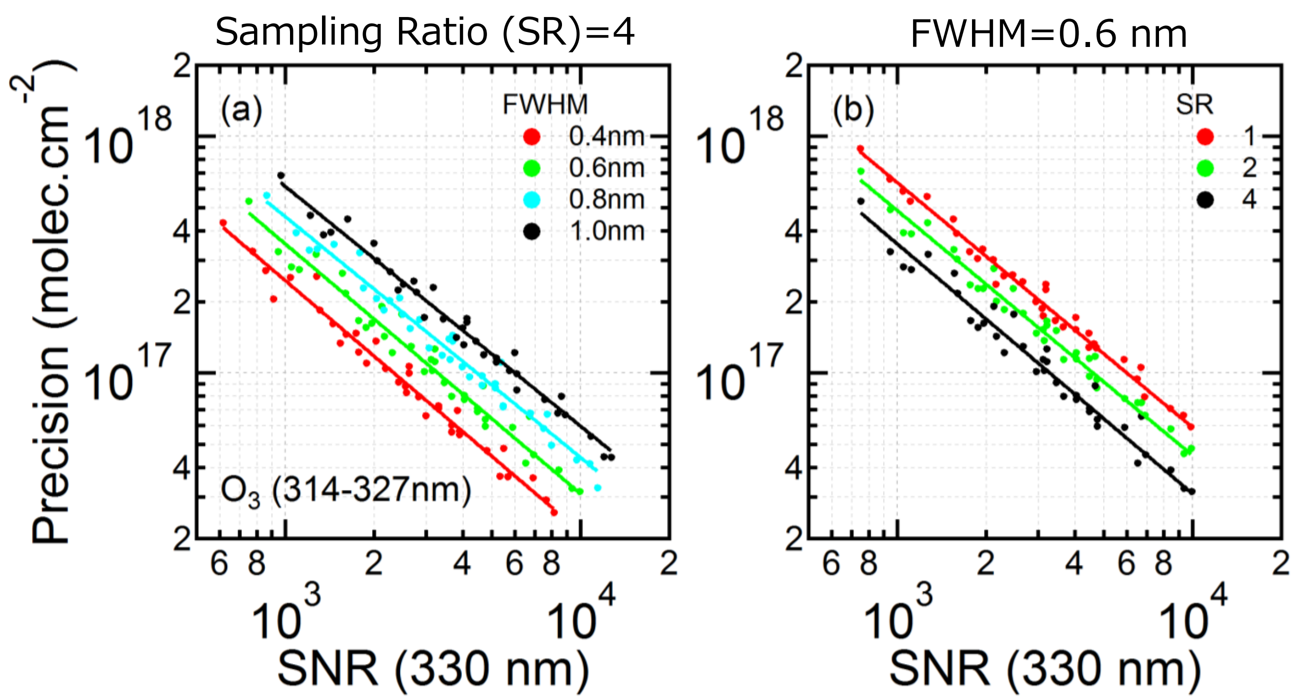
- Fitting window:
  - 314-327 nm for UV O_3 and SO_2

- Degree of offset polynomial : 2nd (i.e., $c(\lambda) = a_0 + a_1\lambda + a_2\lambda^2$)
- Degree of polynomial : 3rd (i.e., $p(\lambda) = b_0 + b_1\lambda + b_2\lambda^2 + b_3\lambda^3$)

- Precision estimate
  - For each geometry and each SNR given, 200 synthetic spectra containing different random noises are analyzed by DOAS.
  - The mean and its 1σ standard deviation for 200 SCDs retrieved are calculated.
  - The 1σ standard deviation is regarded as the precision.

Precision for O_3 SCD vs. SNR (UV)

Irie et al. (2012)



- We found clear relationships between the precision(ε) and SNR.
- For example, the precision and SNR are linked by the equation

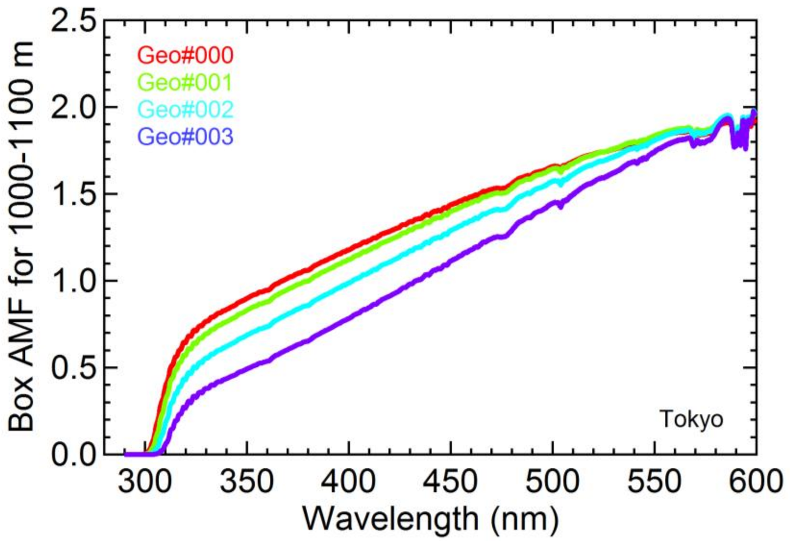
$$\log(\varepsilon) = -1.06 \cdot \log(SNR) + 20.57$$

for O_3 observations in the UV region at a FWHM = 0.6 nm and SR = 4.

- Better precision at better FWHM and larger SR (sampling ratio).

How to use the equation:
example of the application to GMAP-Asia

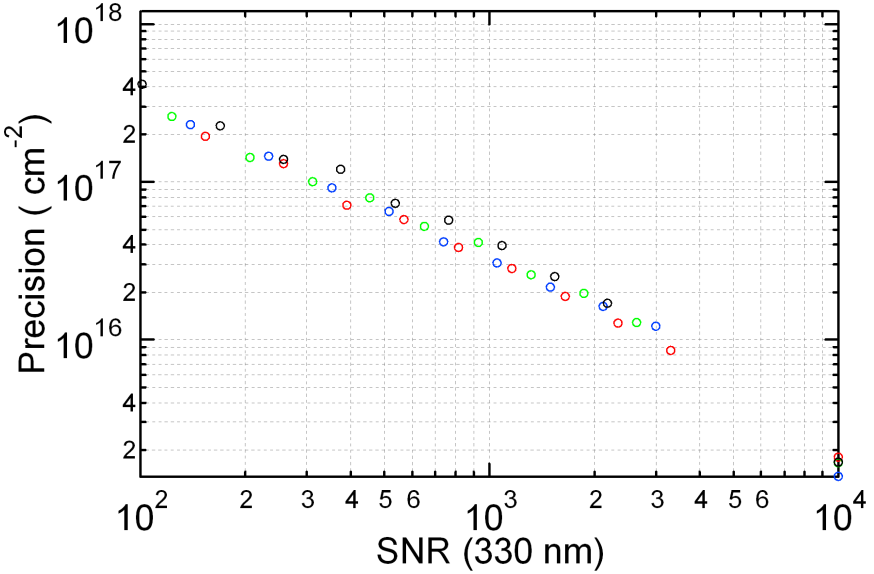
- For GMAP-Asia, the precision required to detect high-ozone events in PBL has been tentatively set to **50 ppbv** (extra-success case).
- This corresponds to a change in **O_3 VCD by 2.5×10^{17} molec. cm^{-2}** or a change in **O_3 SCD by 1.25×10^{17} molec. cm^{-2} (box-AMF at 1 km is about 0.5)**.



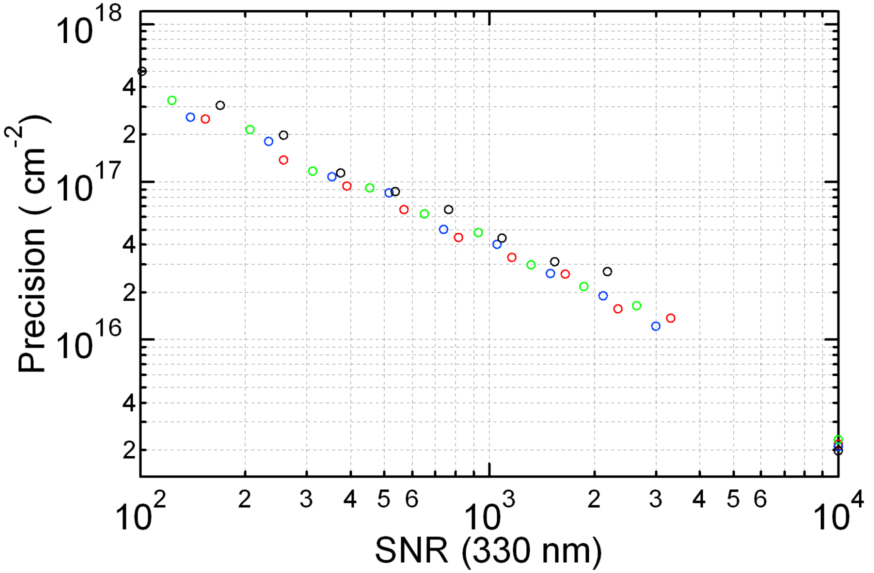
- The change in SCD is regarded as ε.
- Putting the ε into the equation **$\log(\varepsilon) = a\cdot\log(SNR) + b$** (where a=-1.06 and b=20.57 for FWHM=0.6 and SR=4), we can obtain the required SNR.

Results for SO_2

FWHM=0.4 nm



FWHM=0.6 nm



For SO_2, clear relationships between the precision(ε) and SNR are also seen!

SNRs corresponding to the requirements

This study

Requirement
PBL SO_2 = 10 ppbv
SO_2 VCD = 5.0×10^{16} molec. cm^{-2}
SO_2 SCD = 2.5×10^{16} molec. cm^{-2}

SNR(@320nm)
800 for FWHM = 0.4 nm
900 for FWHM = 0.6 nm

Requirement
PBL SO_2 = 4 ppbv
SO_2 VCD = 2.0×10^{16} molec. cm^{-2}
SO_2 SCD = 1.0×10^{16} molec. cm^{-2}

SNR (@320nm)
1900 for FWHM = 0.4 nm
2400 for FWHM = 0.6 nm

※SNR(@320nm) converted from SNR(@330 nm)

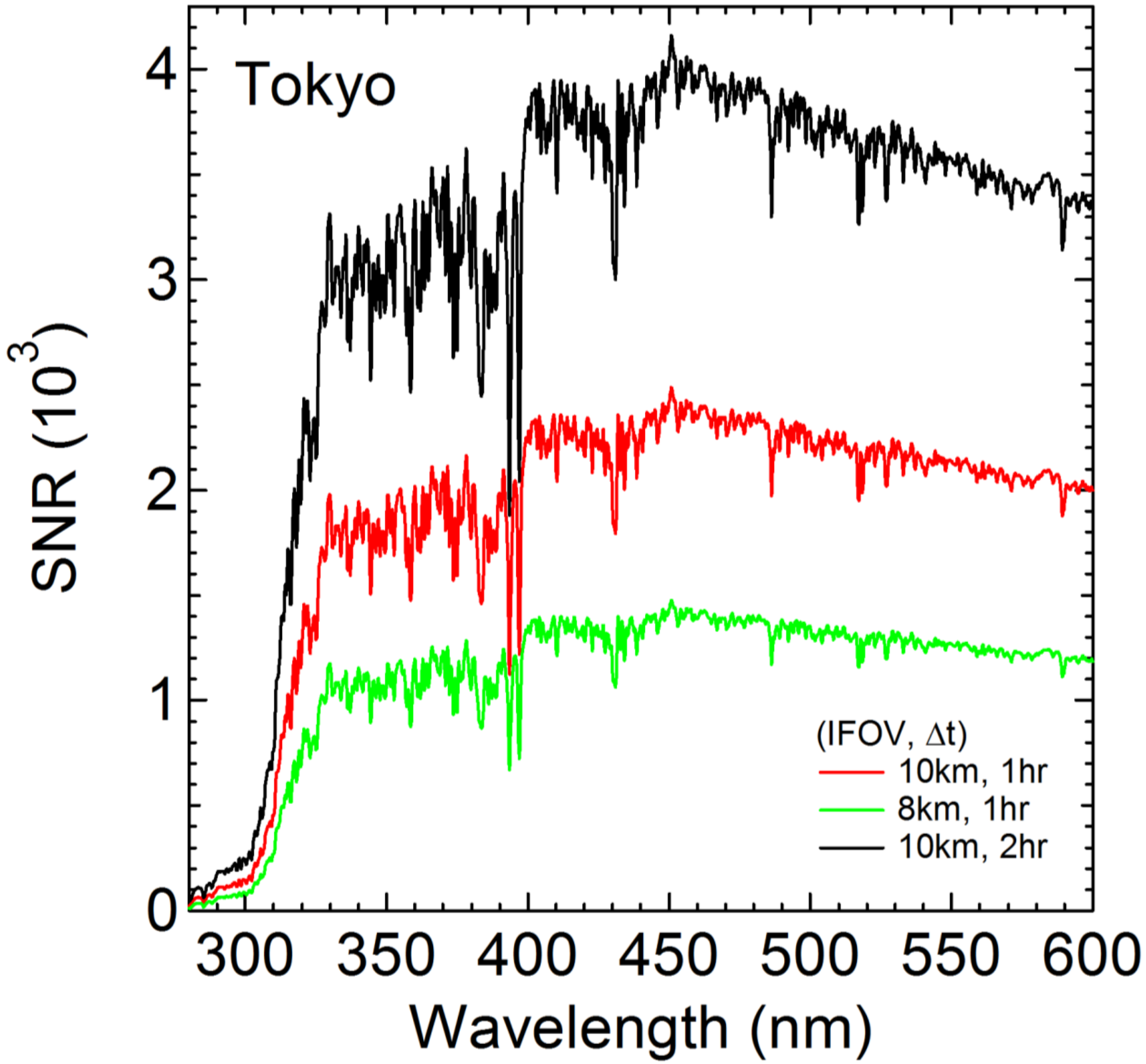
KC and GIST

Requirement
PBL SO_2 = 13 ppbv

SNR (@320nm)
732 for FWHM = 0.6 nm

Requirement
PBL SO_2 = 4 ppbv

SNR (@320nm)
1750 for FWHM = 0.6 nm


Tokyo
SNR (10^3)
Wavelength (nm)
0
1
2
3
4
300
350
400
450
500
550
600
(IFOV, Δt)
10km, 1hr
8km, 1hr
10km, 2hr