Quantifying the relationship between the measurement precision and specifications of a UV/visible sensor on a geostationary satellite

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Introduction

To investigate the feasibility of new satellite observations, including air quality (AQ) observations from geostationary (GEO) orbit, it is essential to link the measurement precision (ε) with sensor specifications in advance. The present study attempts to formulate the linkage between ε and specifications of a UV/visible sensor (signal-to-noise ratio (SNR), full width at half maximum (FWHM) of the slit function, and sampling ratio (SR)) on a GEO satellite.

Method

A sophisticated radiative transfer model (JACOSPAR) is used to calculate synthetic radiance spectra that would be measured by a UV/visible sensor observing the atmosphere over Tokyo (35.7°N, 139.7°E) from GEO orbit at 120°E longitude. The spectra, modified according to given sensor specifications, are analyzed by the differential optical absorption spectroscopy technique to estimate the ε for slant column densities of O₃ and NO₂.

For evaluations of O₃(UV), O₃(visible), and NO₂, fitting windows at 314-327 nm in the Huggins bands, 450-550 nm in the Chappuis bands, and 425-450 nm were analyzed respectively. Two hundred spectra were analyzed by the DOAS method for each of the different sensor specifications and geometries. The precision was estimated simply as the 1σ standard deviation of 200 retrieved SCDs.

Relationships between the precision and sensor specifications

We find clear relationships: for example, the ε of the slant column density (molecules cm⁻²) and SNR at 330 nm are linked by the equation \( \log(\varepsilon) = -1.06 \cdot \log(SNR) + 20.57 \) for O₃ observations in the UV region at a FWHM = 0.6 nm (for the Gaussian slit function) and SR = 4. The relationships are mostly independent of other specifications (e.g., horizontal and temporal resolutions), as they affect ε primarily through SNR, providing constraints in determining the optimal SNR (and alternatively FWHM and SR) for similar UV/visible sensors dedicated for AQ studies.

Application to GMAP-Asia, the Japanese GEO mission

We propose that the fitted coefficients, a and b, for different FWHMs and SRs, given in Table 2 can be used to infer the required SNR. To demonstrate this, we selected GMAP-Asia as an example, for which the precision required to detect high-ozone events in PBL has been tentatively set to 50 ppbv (extra-success case). For the vertical profile of O₃ assumed in JACOSPAR, the variation by 50 ppbv in the PBL leads to a change in a total VCD of O₃ by 2.5×10¹⁷ molecules cm⁻² or a change in SCD O₃ by 1.25×10¹⁷ molecules cm⁻². The change in SCD was estimated assuming that the box-AMF value for the PBL can be approximated by the layer 1.0-1.1 km calculated by JACOSPAR. The value was calculated to be about 0.5 at 314-327 nm. The change in SCD O₃ corresponds to the required precision. The required SNRs at SR = 4 are readily calculated from a given ε value of 1.25×10¹⁷ molecules cm⁻² to be about 1900, 2600, 3500, and 5000 for FWHM = 0.4, 0.6, 0.8, and 1.0 nm, respectively. Larger SNRs are required at a SR = 2, which yields the required SNRs of about 2500, 3900, 5000, and 6700, respectively. Thus, we could conclude that the SNR at 330 nm should be, at least, as high as ~1900 to meet the scientific requirements in GMAP-Asia.

Conclusions

It is obvious that SNR plays the predominant role in determining the precision ε, followed by FWHM and SR. At constant FWHM and SR, the relationship between ε and SNR can be approximated well by the equation \( \log(\varepsilon) = a \cdot \log(SNR) + b \) using the coefficients given in Table 2. Thus, the estimate using this equation is, at least, expected to provide a necessary condition for on-going/future sensor developments.