# GEO-CAPE UV/Visible Trace Gas Measurements: A Progress Report

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## Abstract/Summary

We present calculations of the sensitivity of ultraviolet and visible radiances to trace gas absorption for planetary boundary layer concentrations of the trace gases which are optically thin in absorption. This class of absorbers includes $NO_2$, $SO_2$, HCHO, and CHOCHO, in other words, all primary tropospheric absorbers in the UV/visible except for $O_3$, which is the subject of separate GEO-CAPE studies presented here. BrO is included as well, due to substantial recent interest in PBL/tropospheric BrO.

Sensitivities are presented as *scattering weights W (λ)* for absorption in a 1 km thick boundary layer, where $W(\lambda) = -\partial \ln I_B / \partial \tau$, where $I_B$ is the back scattered radiance and $\tau$ is the optical thickness for boundary layer absorption. Scattering weights are thus the equivalent of *air mass factors* (AMFs) for absorption in a single layer. AMFs for the entire atmosphere are constructed as a weighted sum of scattering weights (weighted by vertical concentration profile).

Scattering weights are calculated with LIDORT, using a modification of the recently-developed GEO-CAPE tool. Aerosol and $O_3$ are from GSFC: profile1_03jun09.dat. Z, P, T are from the U.S. Std. Atmosphere.

The scattering weights are to be contrasted with geometric absorption: A geometric AMF is, for a plane-parallel atmosphere, $AMF_g = \sec(SZA) + \sec(VZA)$, where SZA is the solar zenith angle and VZA is the viewing zenith angle. Weights are shown vs. *effective solar zenith angle* (ESZA), where $ESZA = \sec^{-1}(\sec(SZA) + \sec(VZA) - 1)$.

These studies follow our successful developments (since 1985, with SAO as U.S. investigator) of SCIAMACHY, GOME-1, and GOME-2, plus participation in OMI and OMPS. Retrievals involved development of algorithm physics coupled with chemistry and transport modeling (in collaboration with the Harvard Modeling Group), and multiple-scattering radiative transfer calculations (LIDORT). Molecules shown here are all now successfully fitted in satellite spectra and, in most cases, made operational.

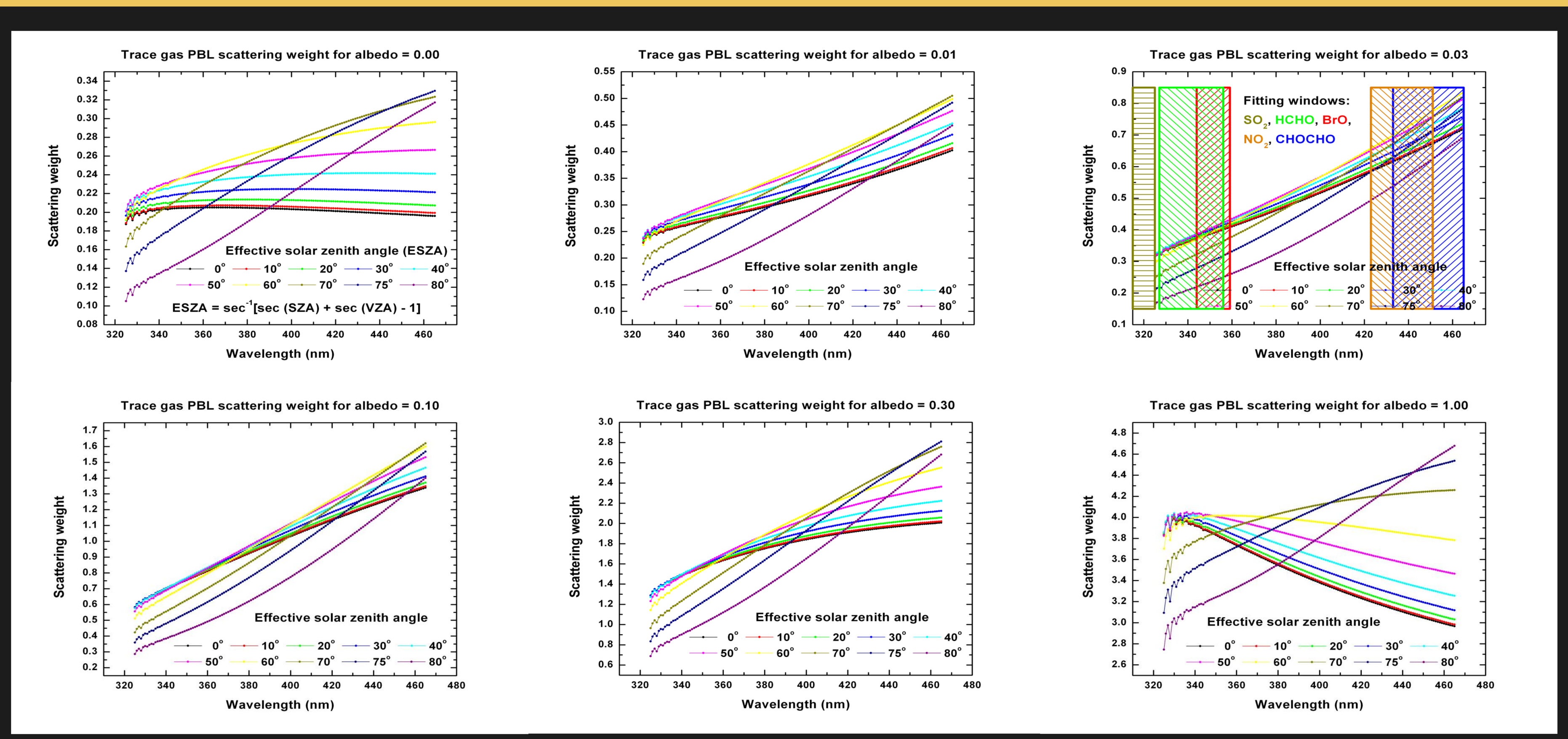
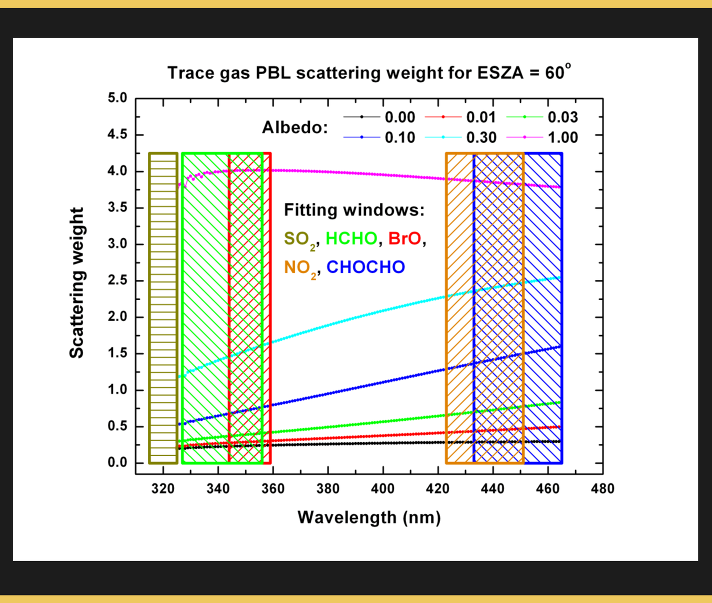



Figure 1. Scattering weights vs. wavelength for optically thin absorption by trace gases in a 1 km PBL, for the complete range of Earth albedos (surface reflectivities). For each albedo, the scattering weight is given for effective solar zenith angles from 0° – 80°, greater than the full range expected to be specified for GEO-CAPE requirements. For albedo = 0.03 (the closest to the average land surface value, fitting windows for the various trace gases are shown.

Figure 2. Scattering weights vs. wavelength for EZSA = 60°, appropriate to mid-afternoon measurements for 40° N/S at the equinox. Fitting windows for the various trace gases are included.

The geometric AMF for this ESZA = 3.




## Previous Retrieval and Instrument studies

Figure 3 shows examples of our retrievals from the GOME, SCIAMACHY, and OMI instruments. The capability developed for these instruments has also been deployed for our previous strawman instrument study, reviewed here, and the ongoing $O_3$ and trace gas calculations. For most trace gases ($NO_2$, HCHO, CHOCHO, BrO) the best retrieval results come from directly fitting L1b radiances. The best $O_3$ and $SO_2$ retrievals from satellite spectra come from direct profile retrievals using optimal estimation

Table 1 shows PBL UV/visible measurement requirements derived from scientific studies using GOME, SCIAMACHY, and OMI measurements. Note that improvement of these (and IR) requirements, an outstanding GEO-CAPE need, is underway in the development of the atmospheric STM. The European requirements for Sentinel 4&5 are also shown.

Figure 4 shows absorption optical thicknesses for the trace gases for typical GEO-CAPE viewing geometry and concentrations. Figure 5 illustrates the range of radiance wavelengths, along with fitting windows in the current SAO strawman instrument concept.

Slant column measurement requirements come from full multiple scattering calculations, including gas loading, aerosols, and the GOME-derived (Koelemeijer *et al*., 2003) albedo database, and assume a 1 km boundary layer height. These are translated into instrument requirements for measuring the geographic area shown in Figure 6 with time resolution of ½ hour up to 70° solar zenith angle (full details available, just ask). Resulting requirements for telescope optics are summarized in Table 2.

Figure 3. Examples of GOME, SCIAMACHY, and OMI retrievals.

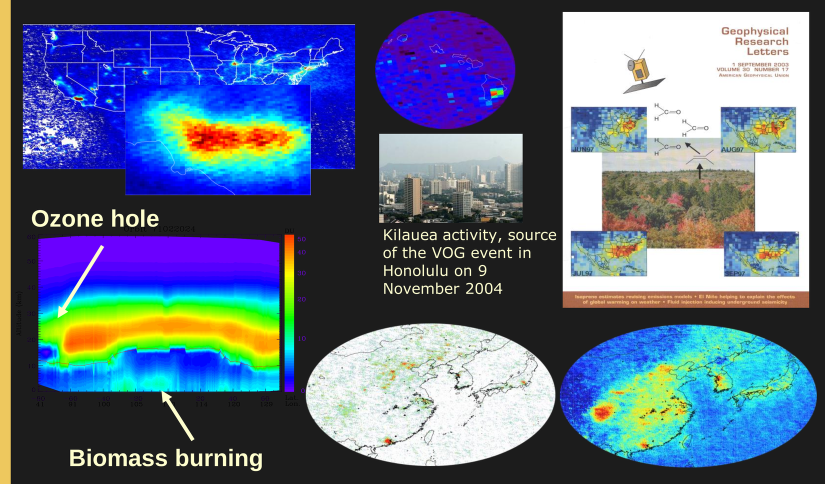



Table 1. Required Concentrations*
European Requirements‡

| Molecule | Vertical Column [mol cm$^{-2}$] | Sensitivity Driver |
|---|---|---|
| $O_3$ | $2.4\times10^{16}$<br>10-25% | ~10ppbv in PBL; reality (profiling) is more complicated<br>10% of PBL; 20% of free trop; 25% of troposphere |
| $NO_2$ | $3.0\times10^{15}$<br>$1.3\times10^{15}$ | distinguish clean from moderately polluted scenes<br>10% of PBL; 20% of free trop; $1.3\times10^{15}$ ≡ background |
| $SO_2$ | $1.0\times10^{16}$<br>$1.3\times10^{15}$ | distinguish structures for anthropogenic sources<br>20% of PBL; 20% of free trop; $1.3\times10^{15}$ ≡ background |
| HCHO | $1.0\times10^{16}$<br>$1.3\times10^{15}$ | distinguish clean from moderately polluted scenes<br>20% of PBL; 20% of free trop; $1.3\times10^{15}$ ≡ background |
| CHO-CHO | $4.0\times10^{14}$<br>n.a. | tracking of most urban diurnal variation<br>n.a. |

*In PBL. One of two issues needing the most work (traceability from AQ reqs and modeling)

‡AQ requirements from CAPACITY; Mission Requirements for Sentinel 4&5: Generic at present ($1.3\times10^{15}$ = 1 ppbv in 0.5 km). Need further consideration of actual AQ requirements and flowdown to measurement requirements

Figure 4. Absorption optical thicknesses for GEO-CAPE for GEO-CAPE trace gases at typical concentrations

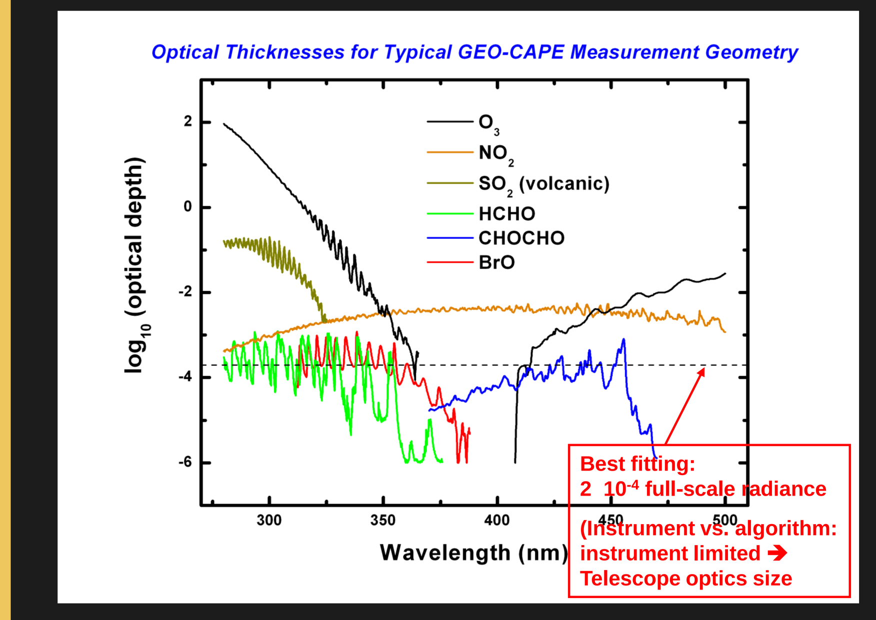



Figure 5. Radiance wavelengths for the GEO-CAPE strawman concept, with GOME, SCIAMACHY, OMI fitting windows

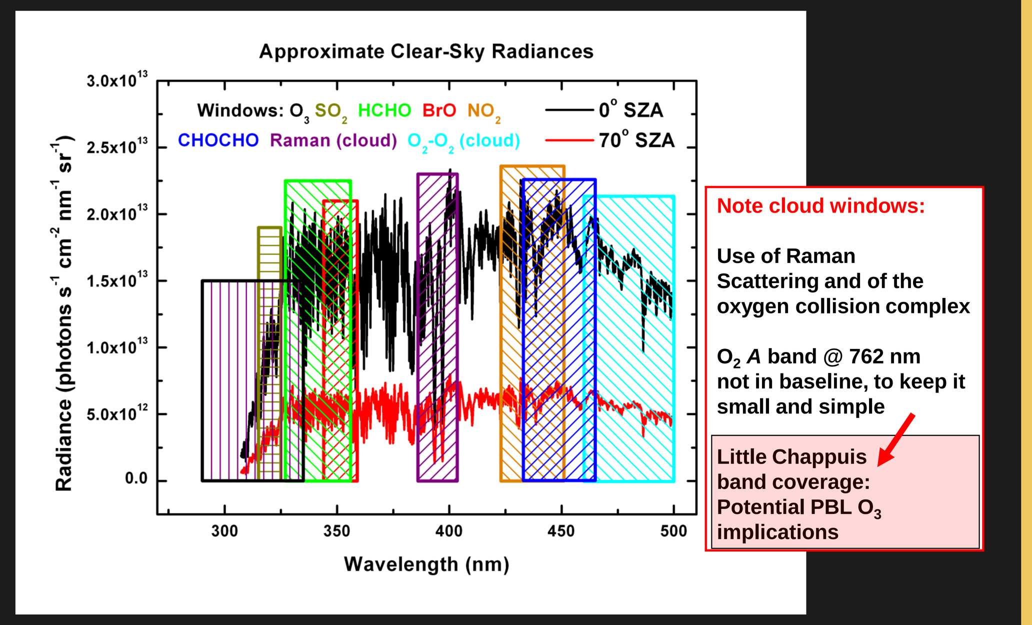



Figure 6. Geophysical extent of the geostationary minimum case for GEO-CAPE measurements.

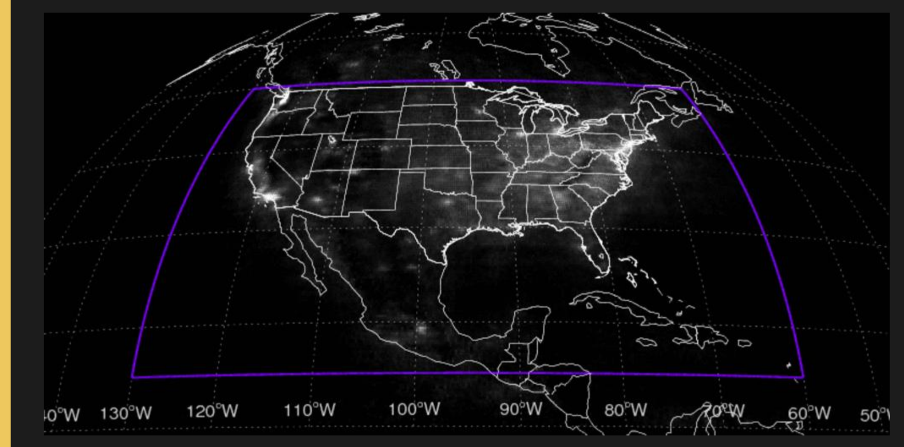


Table 2. Telescope optics sizing for 10×10 km² footprint, 1 second integration time, ½ hour revisit of the area in Figure 6.

| Molecule | \|Rad\| | φ cm$^{-2}$ px$^{-1}$ | RMS | φ px$^{-1}$ | $a\times$Eff |
|---|---|---|---|---|---|
| $O_3$ | $3.57\times10^{12}$ | $2.51\times10^{4}$ | $1.40\times10^{-3}$ | $1.28\times10^{5}$ | 5.09 |
| $NO_2$ | $6.25\times10^{12}$ | $4.87\times10^{4}$ | $8.99\times10^{-3}$ | $3.09\times10^{3}$ | 0.063 |
| $SO_2$ | $2.94\times10^{12}$ | $2.06\times10^{4}$ | $7.25\times10^{-3}$ | $4.76\times10^{3}$ | 0.230 |
| HCHO | $5.65\times10^{12}$ | $3.97\times10^{4}$ | $5.51\times10^{-4}$ | $8.23\times10^{5}$ | 20.8 |
| CHO-CHO | $6.22\times10^{12}$ | $4.85\times10^{4}$ | $3.56\times10^{-4}$ | $1.98\times10^{6}$ | 40.7 |

$a\times$Eff = Telescope collecting area (cm²) × overall optical efficiency

20.76 cm² is a 16-cm diameter telescope @ 10% optical efficiency (GOME, a much simpler instrument, is 15–20% efficient in this wavelength range).

## SAO Strawman update

Compared to previous SAO scalable strawman: Fitting HCHO to $1\times10^{16}$ cm$^{-2}$ precision with 3-hour repeat time for SZA ≤ 50° and for 8×8 km² resolution minimally Nyquist sampled (to 4×4 km²), the revised telescope optics diameter is 12 cm. If $2.5\times10^{15}$ cm$^{-2}$ precision is required, the revised telescope optics diameter is 48 cm. 12 cm corresponds to the most likely reading of the STM.

If $O_3$ is required every hour to $2.4\times10^{16}$ cm$^{-2}$ precision in the PBL (10 ppbv), $O_3$ becomes the driver, requiring a 17 cm diameter telescope.

## Future Studies

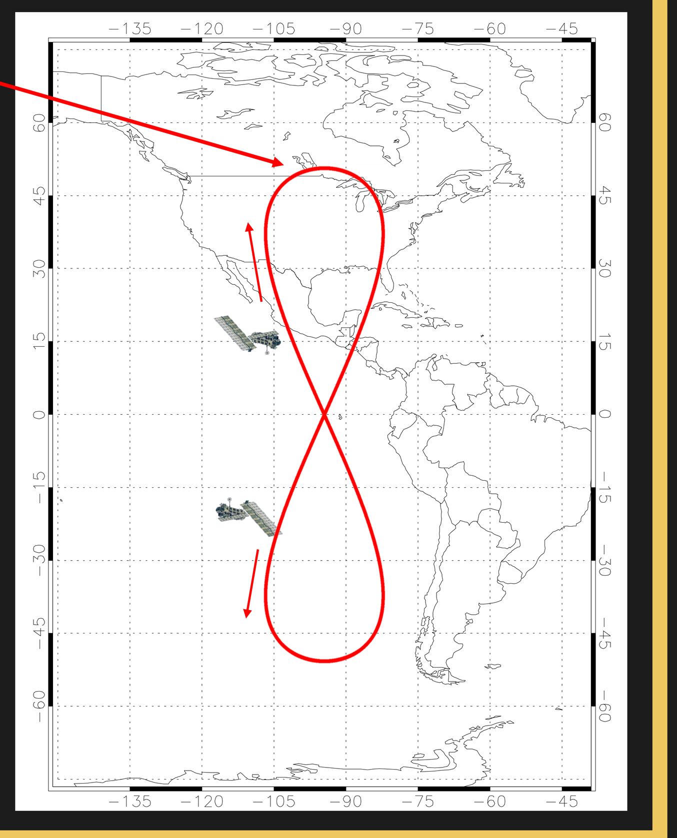
Trace gases
- Other atmospheres, full range of geophysical conditions
- Scattering weights for full troposphere, plus AMFs
- Coordinated with STM development
  - -Pointing, sampling,
- Ocean STM developments

Instrument Design
Reducing "smile", enabling multiple readouts, increasing efficiency, optimizing ITF shape …
*The single most important outstanding issue in demonstrating the feasibility of geostationary pollution measurements.*

## Alternative Orbit – Inclined Geosynchronous

Geostationary orbits suffer from high VZAs at high latitudes, a particular difficulty for Europe. An inclined geosynchronous orbit (50° inclination shown here) is an attractive way to address this difficulty.

***Above the U.S. - Canadian border, e.g. at noon***



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