Detectability of \(O_3\) and CO in the near-infrared: Implications for measurements from GEO-CAPE

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Assessing the feasibility of a near-IR \(O_3\) & CO retrieval

- Determining the measurement sensitivity to lowermost troposphere (LMT) ozone (\(O_3\)) and carbon monoxide (CO) is important for the characterization of pollutant sources and a priority for GEO-CAPE
- For \(O_3\), this is generally limited by Raleigh scattering in the UV and by lack of thermal contrast between the surface and atmosphere in the thermal-IR (TIR)
- In this study, we perform a radiative transfer study for the NIR to assess the feasibility of making a true total column ozone measurement with LMT sensitivity using solar backscatter in the near-IR (NIR)
- This is a particularly difficult region of the spectrum for nadir remote sensing as it falls at the weak-signal cross-over between the Earth thermal emission and solar backscatter.
- Useful trace gas absorption signatures are also weak
- Here we perform a radiative transfer study for the NIR radiance sensitivity to tropospheric \(O_3\) and CO and calculate radiance Jacobians (weighting functions) to investigate the impact of uncertain knowledge of the surface temperature and reflectivity and water vapor profile
- Demonstrating adequate weighting functions is an essential prerequisite for subsequent retrieval studies

\(O_3\) Bands: Radiance Contributions

<table>
<thead>
<tr>
<th>Band</th>
<th>Contributions</th>
</tr>
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<tbody>
<tr>
<td>3.6 (\mu m)</td>
<td>Reflective solar/Thermal IR and backscattering</td>
</tr>
<tr>
<td>3.27 (\mu m)</td>
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</tr>
</tbody>
</table>

![Radiance Contributions](image)

Total Radiance & Components: Reflective solar/Thermal IR and backscattering

![Total Radiance & Components](image)

Relative strengths of surface radiance source terms

![Relative strengths of surface radiance source terms](image)

Conclusions for surface term study

- Sensitivity to albedo dominates the TOA radiance, followed by the sensitivities to surface temperature and water vapor
- Retrieval over low albedo, high temperature surfaces will be particularly difficult because of the comparable contributions to total signal from thermal and radiative thermal
- This will require both albedo and surface temperature to be known to high accuracy to disentangle the signal components
- Surface heterogeneity for even slightly different FOVs will further complicate matters
- Radiance sensitivity to a 10\% increase in surface ozone (i.e. a 200 ppbv pollution event) is much smaller than the radiance change for a 10\% increase in water vapor, which is lower than the expected error for a nadir water vapor retrieval
- The implications of this water vapor interference for ozone retrieval are studied below

Conclusions for water vapor study

- Even in the “best case scenario” assuming a dry atmosphere and perfect knowledge of surface albedo and temperature, the uncertainty in the water vapor profile alone would most likely prevent the detection of changes in tropospheric \(O_3\) in the NIR
- If the study were taken to the next stage with a retrieval analysis, the radiance error associated with a 10\% water vapor uncertainty alone would most likely prevent the detection of changes in tropospheric \(O_3\)
- As demonstrated here, this radiance error would dominate any forward model radiance change associated with the “forward model component error” in the MAP retrieval measurement error covariance matrix
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- These conclusions do not depend on any proposed instrument description since they essentially assume a perfect instrument with zero noise and monochromatic spectral resolution

Carbon Monoxide Detectability: \(AR\) (for \(A(O_3) \neq 0, CO\) retrieval)

![Carbon Monoxide Detectability](image)

Detectability for 200ppbv CO vs. 10% \(H_2O\) perturbation

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Conclusions for \(O_3\) Bands: Radiance for surface terms

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\(O_3\) Bands: Radiance for surface terms

![O3 Bands: Radiance for surface terms](image)

Detectability for \(O_3\) and CO

![Detectability for \(O_3\) and CO](image)

Comparison of \(O_3\) & \(H_2O\) Jacobians

**Setup:**
- Assume perfect knowledge of albedo (20\%) & surface temperature (276K)
- Because these are the leading terms determining reflected solar and thermal signal components, which may be of comparable magnitude, it will be a prerequisite for \(O_3\) retrieval in this spectral region that both are known to high accuracy
- Calculations for NIR radiance are monochromatic (0.0025 cm\(^{-1}\) resolution) and assume no instrument line-shape or noise
- Assume the minimum requirement for a useful \(O_3\) measurement sensitivity is 20 ppbv given that continental US surface values usually fall in the range 20–70 ppbv
- Also assume that the uncertainty in water vapor profile is 10\% which is optimistic considering current sounding uncertainties (AIRS quotes 15%)
- Line-shape or noise

\(\Delta R(\lambda_3)/\Delta H_2O = 10\%\)

![Comparison of \(O_3\) & \(H_2O\) Jacobians](image)

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![Calculations for \(O_3\) radiance](image)

Ozone Jacobian example

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Objectives

- Essential prerequisite for subsequent retrieval studies
- Detectability remains a viable option at 3\% near the surface
- This is 20 times better than the current state-of-the-art detection accuracy for the 3.5 \(\mu m\) band
- Likely of gas concentration in the case of MOPITT increased detectability to 2.5

![Objectives](image)

**Summary:**
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- Likely of gas concentration in the case of MOPITT increased detectability to 2.5

![Summary](image)