Impact of Water Broadening on Atmospheric CO$_2$ Retrievals for the OCO-2 Mission

F. Oyafuso & Absco team*

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OCO-2 Spectroscopy

OCO precision requirements:
- Goal: 1 ppm (~0.3%)
- Necessitates extreme precision in spectroscopy

Spectroscopy Model:
- 3 bands: WCO$_2$ (1.6μm), SCO$_2$ (2.06μm), O$_2$A (0.76μm)
## OCO-2 Spectroscopy: Updates

<table>
<thead>
<tr>
<th></th>
<th>0.76μm O₂</th>
<th>1.61μm CO₂</th>
<th>2.06μm CO₂</th>
<th>H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spectral range</strong></td>
<td>12745-13245 cm⁻¹</td>
<td>4700-6500cm⁻¹</td>
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<td>12745-13245 cm⁻¹</td>
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<tr>
<td><strong>Spectral resolution</strong></td>
<td>0.01 cm⁻¹ or 0.002 cm⁻¹</td>
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<td><strong>Intensities</strong></td>
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<td><strong>Line shapes</strong></td>
<td>Voigt / Galatry</td>
<td>Speed-dependent Voigt</td>
<td>Speed-dependent Voigt</td>
<td>Voigt</td>
</tr>
<tr>
<td><strong>“ Temp. dep.</strong></td>
<td>Tran (2008)</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td><strong>Speed dep.</strong></td>
<td>-</td>
<td>Devi (2007)¹</td>
<td>Benner/Devi (2011)¹</td>
<td>-</td>
</tr>
</tbody>
</table>
Why worry about $\text{H}_2\text{O}$?

- Water vapor varies greatly both spatially and temporally.
- Spectroscopic errors associated with water vapor can potentially introduce unphysical biases in retrieved $X_{\text{CO}_2}$.
- Effect of water on spectroscopy:
  - Direct absorption
  - Enhanced broadening of $\text{CO}_2$ and $\text{O}_2$.

Two recent publications:
- Sung @ 4.3μm
- Wallace @ 1.6μm (3 lines)

Weak dependence on vibrational quantum number extends applicability to WCO$_2$ and SCO$_2$ bands.

Use a rational function fit to measured water-broadened CO$_2$ lines, $\gamma_{\text{CO}_2\text{--H}_2\text{O}}(J'')$. *

$$\gamma = \gamma_{\text{air}} + (\gamma_{\text{self}} - \gamma_{\text{air}})x_{\text{CO}_2}$$

Water turns out to be a much more effective broadener for CO$_2$ than air (~1.8x).

Until recently, there had been only one publication on H₂O broadening of O₂ (Fanjoux et al, J. Phys Chem, 101, 1061 (1994)). BUT measurements were at high temps 446<T<990K.

This year another result has been published showing a much greater difference from air (Vess et al, J. Phys Chem, 116, 4069 (2012)), but only six transitions were measured.

Enhancements differ considerably: ~8% (Fanjoux), ~80% (Vess)
Effect on single band retrievals

Previously:

- $\text{WCO}_2$ and low optical thicknesses $\rightarrow$ core reduction increases retrieved $X_{\text{CO}_2}$.
- $\text{SCO}_2 \rightarrow$ lines are too saturated for cores to matter, enhance of wings decreases retrieved $X_{\text{CO}_2}$.
- Addition of water continuum in $\text{SCO}_2$ changes things.
- $\text{WCO}_2$, $\text{SCO}_2$ now largely cancel.
Residuals are not improved for single band XCO2 retrievals – they worsen slightly.
3 band retrieval complicates analysis:

- Previous slides show $W_{CO_2}$, $SCO_2$ may cancel.
- Fanjoux $O_2$-$H_2O$ broadening enhancement is small $\rightarrow$ little dependence on $H_2O$ column
- If 1.8x approximation (Vess) is valid, $XCO_2$ spectroscopic error can exceed 1ppm.
Apart from isotopic abundances, no additional scaling used:

- Retrieved surface pressure agrees well with ECMWF:
  - 1.8x enhancement of dry air broadening reduces bias in retrieved surface pressure.
- However, ~2.5ppm bias exists in XCO2
- Dependence on water column: -0.09 ppm/(g/cm²) → +0.22 ppm/(g/cm²)
Summary

- Capability of modeling water dependent cross sections has been included in the L2 algorithm for OCO-2
- Characterization of H2O-broadened O2 is very uncertain, ...
- … but, if not accounted for, could introduce spatial or temporal biases exceeding the OCO-2 error budget.
- Further lab measurement may be needed to settle the issue.

Acknowledgements

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