Impact of the improvement of collision induced absorption in the O₂ A-band on the retrieval of OCO-2 dry air column of CO₂

The knowledge of atmospheric absorption by O₂ in the 0.76 μm is critical for NIR+SWIR space mission dedicated to greenhouse gas column retrievals.

In this work we propose an empirical improvement to Tran and Hartmann 2008 collision induced absorption (CIA) in the O₂ A-band that was fitted on TCCON spectra of various airmasses.

This LMD 2019 improvement of the CIA yields:
- reduced averaged calc-obs spectral residuals on 325 Parkfalls TCCON spectra
- reduced airmass dependance of fitted O₂ profile scaling factors on TCCON spectra
- Improved OCO-2 raw XCO₂ bias relative to TCCON compared to Tran and Hartmann 2008
Impact of the improvement of collision induced absorption in the $O_2$ A-band on the retrieval of OCO-2 dry air column of $CO_2$

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Contents

• Introduction

• Evaluation of spectroscopy: the SPARTE chain

• Improved effective collision induced absorption in the $O_2$ A-band: LMD 2019

• Airmass dependance of $O_2$ scaling factors retrieved from the $O_2$ A-band of TCCON spectra

• $XCO_2$ retrieval from OCO-2 spectra

• Conclusions and future works
Introduction

In NIR + SWIR space missions designed to retrieve the column averaged dry-air mole fraction of CO$_2$ (XCO$_2$), the O$_2$ A-band at 0.76 µm enables to retrieve the amount of dry air.

The knowledge of atmospheric absorption by O$_2$ in this spectral region is thus critical to yield relevant XCO$_2$ values.

Two different models of atmospheric absorption exist in this spectral region:

• **Tran and Hartmann, 2008**: O$_2$ spectral lines + Line-Mixing (LM) model + collision induced absorption (CIA), all determined from laboratory measurements

• **Drouin et al, 2017**: self-consistent package of O$_2$ spectral lines (speed dependent Voigt profile) + modified Tran Hartmann LM model (determined from laboratory measurements) + effective CIA model (fitted from TCCON spectra)
Evaluation of spectroscopy: the SPARTE chain (1/2)

**SPARTE:** Spectroscopic Parameters and Radiative Transfer Evaluation [Armante et al, 2016, JMS]

Observations: *TCCON*

- Quality filtering
  - Clear observed spectra

*TCCON a posteriori state*

- Statistical analysis
  - (bias and standard deviation)
  - Differences "calc-obs"

- Observed spectra
- Simulated spectra

- T, gas
- 4A/OP

- Spectroscopic databases
- Instrumental parameters

We adapt the SPARTE chain to spectroscopy evaluation from TCCON spectra: we can compare the impact of different CIA models with this tool. It can be used with any radiative transfer model, instrumental model and spectroscopic input.
Though lower in amplitude, residuals with Drouin 2017 show "negative over-corrections" in several spectral regions.
Improved effective collision induced absorption in the $O_2$ A-band: **LMD 2019** (1/2)

We fit on Parkfalls TCCON spectra of various airmasses an empirical correction to Tran and Hartmann 2008 measured collision induced absorption model, yielding the **LMD 2019** improved CIA.

This **LMD 2019** empirical CIA is intended to improve residuals compared to Tran and Hartmann 2008 without resulting in the previously seen "negative over-corrections".
The **LMD 2019** empirical CIA correction brought to **Tran and Hartmann 2008** improves residuals while not "over-correcting" to negative residuals values previously pointed spectral areas.
Airmass dependance of O$_2$ scaling factor retrieved from TCCON O$_2$ A-band spectra (1/3)

As performed by ggg2014, the official TCCON processing algorithm [Wunch et al, 2011, 2015], in the 1.27 µm spectral region, we retrieve an O$_2$ profile scaling factor from TCCON spectra 0.76 µm spectral region in order to examine the airmass dependance of Tran and Hartmann 2008, Drouin 2017 and LMD 2019 CIA versions. For this purpose we use an optimal estimation inverse scheme based on 4A/OP radiative transfer and GEISA spectroscopic database set up to perform a 1 Gauss-Newton iteration retrieval.

\[
\text{State} = \begin{bmatrix}
\cdot \text{O}_2 \text{ profile scaling factor}
\end{bmatrix}
\]

A priori atmosphere:
similar to ggg2014

A priori uncertainty:
1.e+06
(basically unconstrained)

Data

325 Parkfalls TCCON spectra measured by the Si-diode instrument between 12,950 – 13,175 cm$^{-1}$, spanning various airmasses.

Selection filters on TCCON measurement parameters and ggg2014 results:
- fractional variation of solar intensity < 0.5
- ggg2014 XCO$_2$ ppm error < 1.0 ppm
LMD 2019 CIA correction brought to Tran and Hartmann 2008 reduces the airmass dependance and the overall amount of O₂ scaling required to fit TCCON spectra in the O₂ A-band.
Drouin 2017 full package (CIA + line-mixing + line list) exhibits a stronger airmass dependance than Tran and Hartmann 2008 and LMD 2019.

This stronger behaviour is likely due to the O₂ absorption line-list and line shape used in Drouin 2017 package: replacing Drouin 2017 LM model and effective CIA by LMD 2019’s (empty circles case) does not change the airmass dependance.
XCO$_2$ retrieval from OCO-2 spectra (1/2)

We retrieve XCO$_2$ from OCO-2 target measurements using an inverse scheme$^1$ based on optimal estimation that relies on 4A/OP radiative transfer model, with GEISA spectroscopic database. The state vector and the a priori are the following:

\[
\text{State} = \begin{bmatrix}
\text{T profile shift} \\
\text{H}_2\text{O scaling factor} \\
\text{CO}_2 \text{ profile} \\
\text{Surface pressure} \\
\text{Bandwise albedo} \\
\text{Bandwise albedo slope}
\end{bmatrix}
\]

A priori state and covariance = ACOS

Data

We use OCO-2 target measurements distributed within ACOS v8 retrospective data release.

Selection filters:
- best ACOS cloud and outcome flags
- ACOS retrieved total aerosol optical dept < 0.1
- airmass < 3.0

Posterior filters:
- reduced Chi$^2$ < 7.0
- blended albedo < 0.8

$^1$ An article that introduces this inverse scheme is currently in preparation.
XCO₂ retrieval from OCO-2 spectra (2/2)

**LMD 2019** effective CIA improves raw XCO₂ bias relative to TCCON compared to **Tran and Hartmann 2008** CIA. Both cases, processed using the previously described retrieval scheme based on 4A/OP, show a raw XCO₂ bias inferior to the ACOS algorithm that uses **Drouin 2017**.

**Note:** these three comparisons take into account the same averaging kernel correction as ACOS [O’Dell et al, 2018, Nguyen et al, 2014].

**Note:** these XCO₂ retrievals are the official raw results from ACOS v8 algorithm [O’Dell et al, 2018]. They are produced with a different state vector and retrieval scheme compared to **LMD 2019** and **Tran and Hartmann 2008** corresponding results. A next step will be to use **Drouin 2017** package with the retrieval scheme based on 4A/OP to yield a completely consistent comparison.
Conclusions and future works

- We introduce an empirical correction, **LMD 2019**, brought to **Tran and Hartmann 2008** measured collision induced absorption (CIA).

- This improvement yields improved average residuals on 325 TCCON spectra measured at Parkfalls station compared to **Tran and Hartmann 2008** and **Drouin 2017**.

- **LMD 2019** CIA reduces airmass dependance of O₂ scaling factor fitted on TCCON spectra compared to **Tran and Hartmann 2008** and **Drouin 2017**.

- **LMD 2019** CIA reduces the absolute raw OCO-2 XCO₂ bias relative to TCCON from -1.47 to 1.13 ppm compared to **Tran and Hartmann 2008** over 50 OCO-2 target sessions.

- **Next steps**: larger OCO-2 processing, comparison of OCO-2 and TCCON XCO₂ retrievals using the same LMD retrieval scheme based on 4A/OP and with several spectroscopies as input.

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