The Impact of the TSIS-SIM Data on the OCO-2/OCO-3 Data Analysis

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Measuring CO₂ from Space

**Record** spectra of CO₂ and O₂ absorption in reflected sunlight

**Retrieve** estimates of the column averaged CO₂ dry air mole fraction, XCO₂ over the sunlit hemisphere

**Validate** estimates to ensure XCO₂ accuracy of 1 ppm (0.25%)
Japan’s Greenhouse gases Observing SATellite (GOSAT; left) and NASA’s Orbiting Carbon Observatory-2 (OCO-2; right) are now returning spatially-resolved estimates of column-averaged CO\(_2\) and CH\(_4\) dry air mole fractions, XCO\(_2\) and XCH\(_4\). These estimates are less precise and accurate than ground-based in situ data, but provide high spatial and temporal resolution and greater coverage of the globe.
Persistent XCO₂ Anomalies Provide Insight Into Fluxes
Atmospheric CO₂ Fluxes from Atmospheric Inverse Models

Flux Differences between fluxes derived using ground-based in situ CO₂ and OCO-2 XCO₂
Emission by Local Sources

• Observations from OCO-2 and other GHG satellites are also being used to quantify emissions from urban areas and large fossil fuel-fired power plants

• A principle challenge for these observations is detecting the plumes from the sources above the background in the presence of variable winds

• Near simultaneous observations of co-emitted gases, such as NO$_2$ from TROPOMI are useful for identifying plumes and separating them from the background

OCO-2 XCO$_2$ and S5p XNO$_2$ over Moscow on 25 August 2018 (Reuter et al. (2019).

OCO-2 XCO$_2$ estimates over the Ghent Power Plant in Kentucky on 13 August 2015 (Zheng et al. 2019).
Estimates of XCO₂ are retrieved from spectra of reflected sunlight.

Errors in the solar spectrum can introduce biases and scatter in the XCO₂ estimates.
The Need for an Accurate Description of the Top-of-Atmosphere Solar Flux

Accurate measurements of the top-of-atmosphere solar spectrum play two critical roles in the analysis of the space-based CO$_2$ and CH$_4$ measurements.

• Observations of the solar spectrum provide the primary on-orbit radiometric and spectroscopic calibration standard for both individual instruments and for cross-calibrating instruments on different platforms.
  – Errors in the TOA solar flux in the O$_2$ A-band compromises our ability to characterize the vertical distribution and total optical depth of clouds and aerosols.

• An accurate, high-resolution description of the solar spectrum is also critical for use in the remote sensing retrieval algorithms used to retrieve XCO$_2$
  – The synthetic atmospheric spectrum from the forward model must be convolved with the solar spectrum and instrument spectral response function to simulate the spectrum observed by the instrument.
On-orbit Solar Calibration Operations

- OCO-2 observes the sun through a solar diffuser to collect solar spectra for radiometric and spectroscopic calibration.
- Observations of the sun acquired on ~12 orbits/day are used to track instrument throughput changes over time:
  - Ice build-up on focal plane arrays
  - Optical coating degradation
- Observations of solar spectra reflected by the moon are used to track changes in the throughput of the solar diffuser.
Solar Spectra within OCO-2 Channels

OCO-2 (blue, green, red) and OCO-3 spectra collected during pre-launch testing

O₂ A-Band

1.61 µm CO₂

2.06 µm CO₂
For OCO-2, the solar spectrum is created by convolving a high resolution solar transmission spectrum (Toon et al. 2016) with a radiometrically-calibrated continuum.
Early TSIS SIM Fluxes were Lower than Source SSI in the SWIR

Preliminary

$$\int_{200}^{2400} E(\lambda) \, d\lambda = 96\% \text{ TSI} \quad (1308 \text{ W/m}^2)$$

Peter Pilewskie, LASP
E. Richard et al.: Brightness Temperatures from the Total and Spectral Solar Irradiance Sensor (TSIS) Spectral Irradiance Monitor (SIM) on the ISS show significant differences with the ATLAS 3 results, especially in CO$_2$ channels.
Meftah et al. SOLSPEC Analysis

New values are:

~0.75% higher

~4.5% lower

~8.7% lower

A new reference solar spectrum based on SOLar SPECtrometer (SOLSPEC) instrument of the SOLAR payload on the International Space Station (ISS) also indicated discrepancies with earlier results within the OCO-2 spectral ranges.

{Meftah et al., 2017}

Comparisons of SOLSPEC results (black) and the revised results indicate large differences in the OCO-2 CO₂ channels.
Fitting the TSIS-SIM Results

Eric Richard provided TSIS-SIM solar spectrum and spectral response functions for each OCO-2 spectral channel. These were convolved with the high-resolution OCO-2 solar spectra.
The OCO-2 continuum values were:
- Scaled by a multiplicative offset and slope \((\text{offset} + \text{slope} \times (\lambda - \lambda_{\text{min}}))\),
- Multiplied by the high resolution transmission spectrum
- Convolved with the TSIS-SIM spectral response function (SRF)
- Original OCO-2 L2 continuum plotted in grey,
- Scaled continuum plotted in black,
- High-res OCO-2 solar spectra convolved with TSIS-SIM SRF (blue)

To verify the results, we created a solar flux file with modified continuum values, read it in and showed it reproduced the TSIS-SIM values without any continuum scaling.
A new solar continuum was derived that matched the TSIS-SIM results, when the OCO-2 solar spectrum were convolved with the TSIS-SIM Instrument response function.

**ABO2 Scaling:**
\[(0.987 - 0.3 \Delta \lambda) \times F_{c(\text{old})}, \Delta \lambda = (\lambda - \lambda_{\text{min}}), \lambda_{\text{min}} = 0.751880 \text{ \mu m}\]

**WCO2 Scaling:**
\[(0.97 - 0.11 \Delta \lambda) \times F_{c(\text{old})}, \Delta \lambda = (\lambda - \lambda_{\text{min}}), \lambda_{\text{min}} = 0.1.53846 \text{ \mu m}\]

**SCO2 Scaling:** 0.935 × F_{c(\text{old})}, No slope correction needed
The TSIS-SIM Fits

The resulting high-resolution solar spectrum was generated in each spectral range and used in tests of the new, B10 OCO-2 product.
No significant change in XCO$_2$ between versions of the retrievals with old and new solar fluxes
Other Parameter: Surface Pressure and Wind Speed Changes

Surface pressure changes are small: -0.2 hPa over Land, +.2 hPa over water.

Wind speed over the ocean is calculated using a Cox-Munk model. The reduced solar flux in the SCO2 channel is compensated by a reduced wind speed and increased glint brightness at OCO-2’s glint off-pointing angles.

Le (Elva) Kuai and Brendan Fisher
Changes in the Retrieved Albedos

- Water: Reduced Lambertian term in the O₂ A-Band and 1.61μm CO₂ channels
- No change in the 2.06 µm CO₂ channel because glint albedo set in this channel
- Land: Albedo slightly higher to compensate for lower solar flux.
  - Albedo slopes slightly reduced
Conclusions

- **XCO$_2$**: no significant change.
- **Psurf**: Retrieved P gets slightly closer to a priori
- **Albedo**:
  - Reduced Lambertian term in ABO2 and WCO2 channels over water (as expected)
  - Increased albedo in the SCO2 channel over land, compensating for the reduced flux
- **Wind speed**:
  - A reduced wind speed in the SCO2 channel is needed to increase the glint brightness to compensate for the reduced solar flux in this channel
- **AOD total**:
  - No significant change
- **Recommendation**: Use New solar data in L2 retrieval algorithm
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