Exploring the Sensitivity of Column CO_2 Retrievals From Space To Surface Elevation

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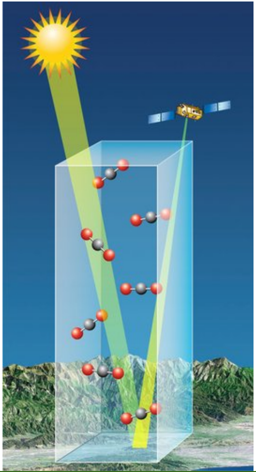
OCO-2 ACOS algorithm



- The NASA Orbiting Carbon Observatory 2 (OCO-2) is a passive polar-orbiting satellite with 3 bands at 0.76 μm (O_2A band), 1.61 μm (weak CO_2 band), and 2.06 μm (strong CO_2 band).

- OCO-2 began collecting data in late 2014 and uses the Atmospheric Carbon Observations from Space (ACOS) algorithm to retrieve total column dry-air mole fractions of CO_2 (X_{CO_2}). The ACOS algorithm was used for GOSAT beginning in 2009 and was modified for use with OCO-2 (O'Dell et al. 2018; O'Dell et al. 2012).

- New updates/versions of the OCO-2 ACOS algorithm are labeled with a B. B10 was released in 2020 and B11 is being processed with a full release scheduled for 2023.

- A global bias correction is applied to all OCO-2 retrievals of X_{CO_2} that corrects for systematic biases from several parameters in the retrieval including surface pressure bias (dp), and also applies a multiplicative scaling based on comparisons to ground-based measurements from the Total Carbon Column Observing Network (TCCON).

Accurate surface pressure is required to retrieve accurate X_{CO_2}

X_{CO_2}: Column average dry air mole fraction, defined as

$$X_{CO_2} = \frac{\text{total column}\,CO_2}{\text{column dry air}} \tag{1}$$

The OCO-2 ACOS B10 bias correction for soundings over land is

$$X_{CO_2} = \frac{X_{CO_2,\ raw} - \text{Feats} - \text{footprint\_bias}}{0.9959} \tag{2}$$

where the divisor is based on a global offset relative to TCCON and

$$\text{Feats} = -0.855(dpfrac) + (\text{other parameters}). \tag{3}$$

To adjust the X_{CO_2} for a different altitude we calculate a new dpfrac term

$$dpfrac = X_{CO_2,raw}(1 - P_{ap,\ sco2}/P_{ret})$$

with an a priori surface pressure in the strong CO_2 band ($P_{ap,sco2}$) that is adjusted to the change in altitude.

Osterman et al. (2020)
Kiel et al. (2019)

Arctic shifts in X_{CO_2} with the recent ACOS update from B10 to B11

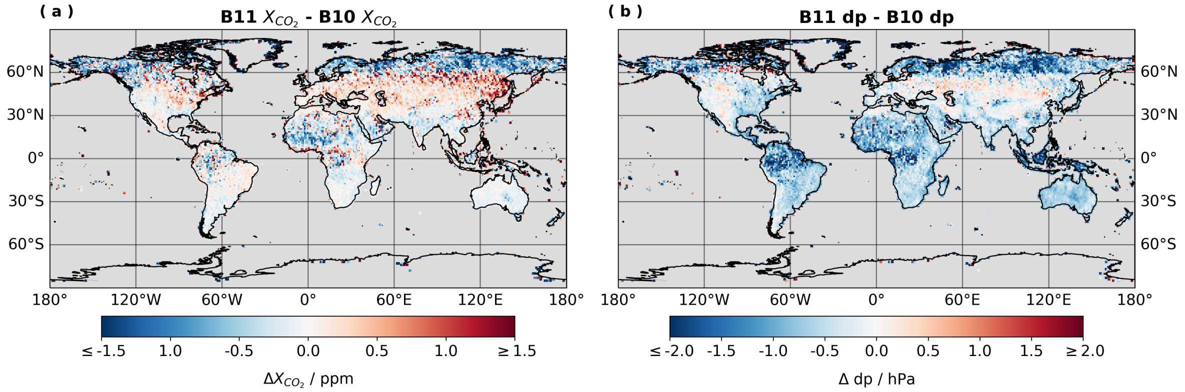


Figure: The difference between OCO-2 B11 and B10 spatial fields of retrieved X_{CO_2} and dp averaged over 2019-04 to 2022-02 and 1°x1° grid with standard OCO-2 quality filters.

- The change from ACOS B10 to B11 yields a significant negative shift in X_{CO_2} and **dp (retrieved - prior surface pressure)**.

Differences in altitude correlate to differences in X_{CO_2} and dp.

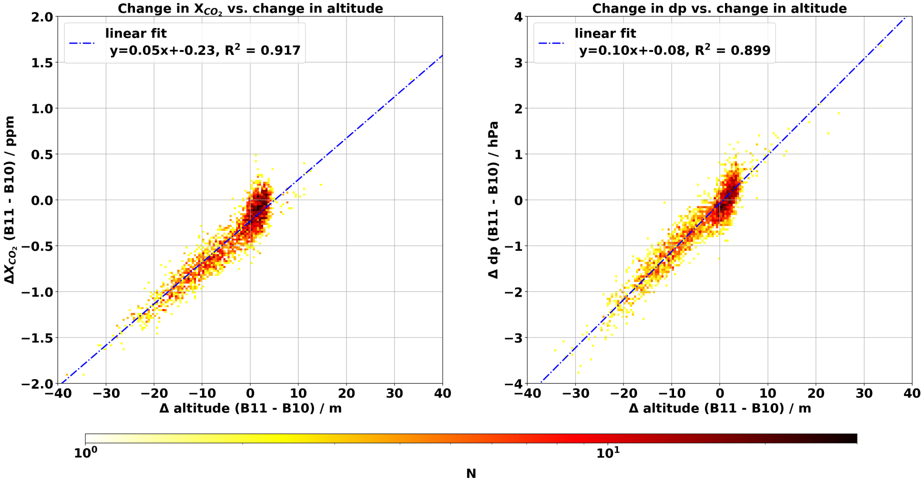


Figure: Change in dp and X_{CO_2} with respect to change in altitude (B11 - B10).

- These plots demonstrate the strong dependence of OCO-2 bias corrected X_{CO_2} and dp (retrieved surface pressure - prior surface pressure) on the referenced DEM.

About the Digital Elevation Models (DEMs)

DEM	Resolution	Resources	Description and validation
B10 DEM	90 m	Zong (2008)	Used for all OCO-2 ACOS versions before B11. It is largely based on data from the 2000 Shuttle Radar Topography Mission (SRTM). Zong 2008
JPL NASADEMplus (B11 DEM)	90 m	Crippen et al. (2016); Simard et al. (2016); Gesch et al. (2016); Abrams et al. (2020)	A conglomeration of 5 distinct DEMs: NASADEM (Crippen et al. 2016; Simard et al. 2016) for most regions within $\pm$ 60° latitude; combination of ASTER v3 30 m DEM (Gesch et al. 2016; Abrams et al. 2020) and ALOS for latitudes from 60°N to 85°N (excluding Greenland).
ArcticDEM	32 m	Claire et al. (2018)	A NGA-NSF public-private initiative using the World-View satellite constellation (different from NASA Worldview website application). Mosaic tile product includes IceSAT altimetry and is available at multiple spatial resolutions from 2 m to 1 km.
Copernicus global DEM	30 m	Fahrland et al. (2020)	A commercial product sold by Airbus and based on TerraSAR measurements. Released to the public in fall of 2021.

DEM differences

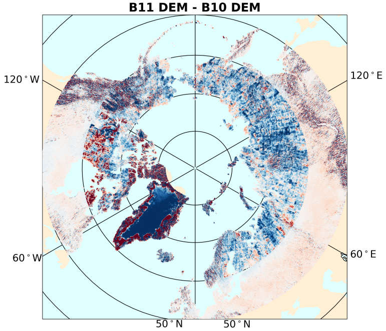


Figure: Difference in elevations between JPL NASADEM30plus (B11 DEM) and the B10 DEM with $0.1^\circ \times 0.1^\circ$ averages.

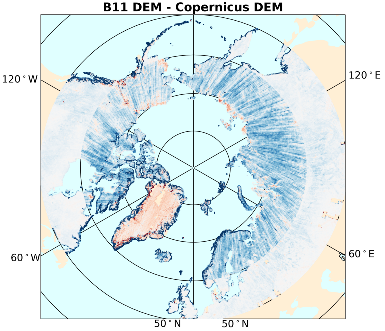


Figure: Difference in elevations between JPL NASADEM30plus (B11 DEM) and the Copernicus DEM with $0.1^\circ \times 0.1^\circ$ averages.

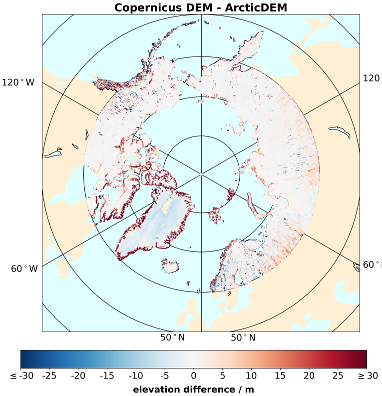


Figure: Difference in elevations between the Copernicus DEM and the ArcticDEM with $0.1^\circ \times 0.1^\circ$ averages.

Copernicus DEM is more consistent across 60°N

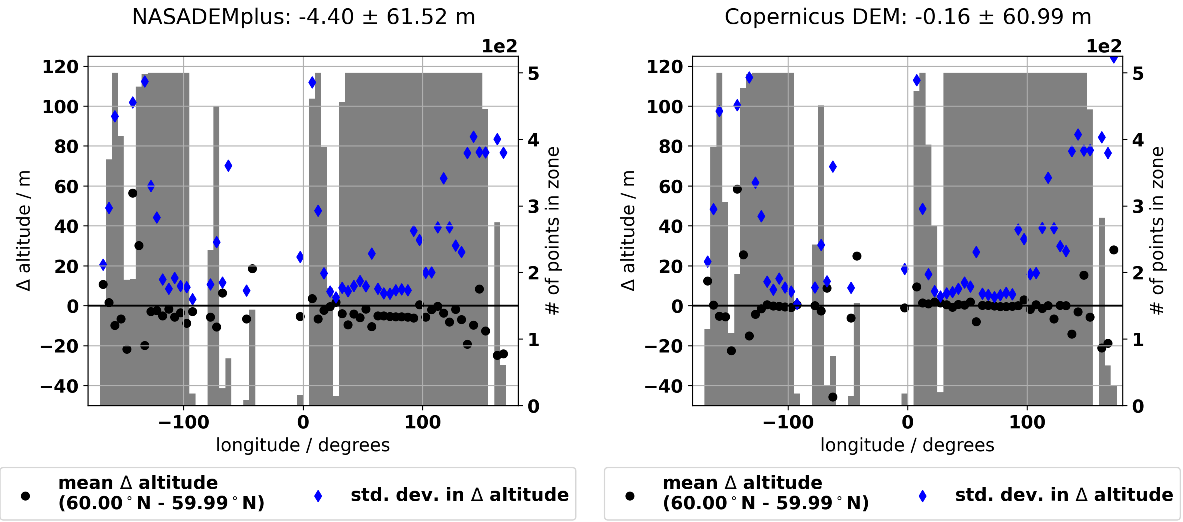


Figure: Differences in elevation between the hundredth degree latitude above and below 60.00°N.

OCO-2 bias with different DEMs

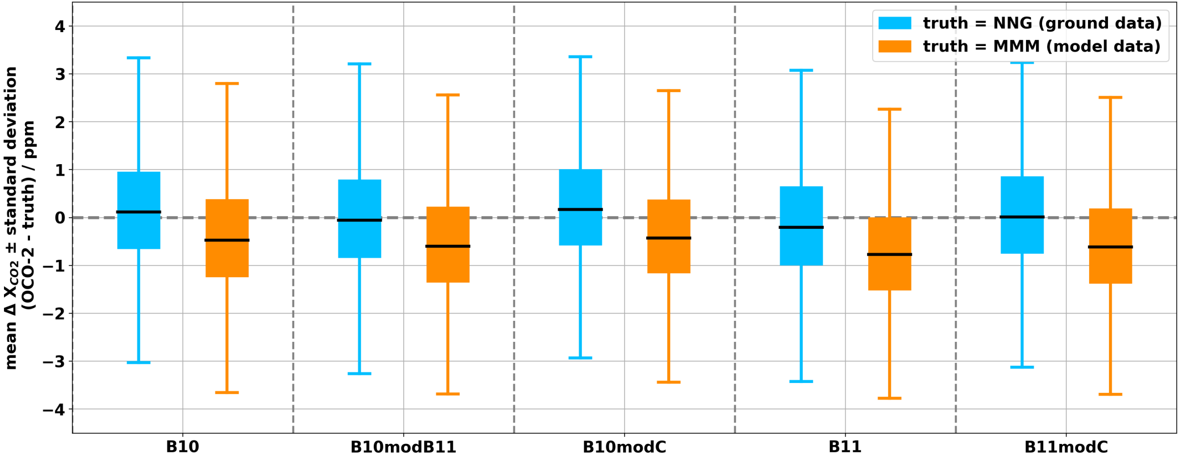


Figure: Bias in X_{CO_2} for variations of B10 and B11 OCO-2 retrievals relative to MMM (multi-model mean, 2019-05 to 2020-12) and NNG (near noon ground-based measurements, 2019-05 to 2021-02). Using the intersection of B10 and B11 xco2_quality_flag filtering.

Conclusions

- Accurate surface pressure is essential for obtaining accurate values of X_{CO_2} (or other X_{gas}).
- The OCO-2 bias correction adjusts retrieved X_{CO_2} to depend less on the retrieved surface pressure and more on the prior surface pressure obtained from a model met field combined with a global DEM.
- A recent update to the OCO-2 ACOS algorithm includes a new DEM with significant changes to elevations north of 60°N, which this corresponds to significant shifts in X_{CO_2} over the arctic regions.
- Despite originating from distinct datasets, the Copernicus DEM and the ArcticDEM are in very close agreement, and both are biased high relative to the NASADEMplus for most regions north of 60°N. In addition, NASADEMplus exhibits an average 4.4 m inconsistency crossing 60°N latitude.
- This and other lines of evidence imply that the DEM used in OCO-2 ACOS B11 has unacceptable errors above 60°N, which directly impact X_{CO_2} quality.
- There is a plan to update B11 lite files to use either the Copernicus DEM or a modified/corrected version of the NASADEMplus, which will include recalculated dp values and a newly calculated bias correction.
- **Note:** Another study on the sensitivity of TROPOMI X_{CH_4} to the DEM over Greenland was also recently published and was part of the motivation for this analysis[1].

[1] J. Hachmeister et al. (2022). "On the influence of underlying elevation data on Sentinel-5 Precursor TROPOMI satellite methane retrievals over Greenland". In: *Atmos. Meas. Tech.* DOI: 10.5194/amt-15-4063-2022.

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