Exploring the sensitivity of northern high latitude retrievals from OCO-2 to the referenced digital elevation model

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Background

- As a polar-orbiting satellite, OCO-2 is in a unique position to provide dense spatial coverage of CO_2 observations over northern high latitude (NHL) regions, if issues of data quality can be addressed.
- Supporting information that is absent or of poor quality adds further challenges to satellite-based trace gas retrievals in high latitude regions, and surface elevations at northern high latitudes have historically been poorly characterized.
- Observations of atmospheric column average dry air mole fractions of CO2 (X_{CO_2}) depend on accurate knowledge of the number density of dry air in the atmospheric column, which requires accurate knowledge of surface pressure.
- In OCO-2 retrievals, prior estimates of surface pressure are based on the GEOS-FP model and adjusted to the average elevation in the satellite footprint based on a **digital elevation model (DEM)**. A global empirical bias correction is applied to the retrieved X_{CO_2}, after the fact, that has the effect of moving the density of dry air in the column closer to that implied by the prior surface pressure and away from that implied by the retrieved surface pressure. As a result, an accurate DEM is essential for defining an appropriate bias correction for northern high latitude retrievals from OCO-2.

Digital elevation models (DEMs)

- The DEM used in B10 was developed in the early 2000's and has not been updated since the first implementation of the ACOS retrieval algorithm for OCO-2. In OCO-2 B11 (not yet released) the DEM has been updated, and now uses the NASADEM30 [3, 5] for most regions within ± 60° latitude, while using elevations provided by the ASTER v3 30 m DEM [4, 1] for latitudes from 60°N to 85°N (excluding Greenland). Elevations for Greenland and Antarctica are from other data sources, but are less relevant to this analysis given their very sparse OCO-2 coverage.
- The Arctic DEM [2] is a NGA-NSF public-private initiative using the WorldView satellite constellation (different from NASA Worldview website application). The mosaic tile product includes IceSAT altimetry and is used here at 32 m resolution.
- For the maps of DEM differences elevations are aggregated to 0.1°x0.1° averages. For the changes in X_{CO_2}, sounding latitudes are paired with a 0.01°x0.01° aggregated grid of the B11 DEM and paired with a 0.1°x0.1° aggregated grid of the Arctic DEM. All B10 altitudes are pulled from the B10 retrievals because we do not have access to the original DEM.

Calculating change in X_{CO_2}

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

$$X_{CO_2} = \frac{X_{CO_2,\ raw} - \text{Feats} - \text{footprint\_bias}}{0.9959} \quad (1)$$

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

$$\text{Feats} = -0.855(dpfrac) + 0.335(\max(\ln(DWS), -5) + 5) - 0.0335(co2\_grad\_del - 5) + 5.2(aod\_fine - 0.03). \quad (2)$$

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

$$dpfrac = X_{CO_2,raw}(1 - P_{ap,\ sco2}/P_{ret}) \quad (3)$$

with an a priori surface pressure in the strong CO_2 band ($P_{ap,sco2}$) that is adjusted to the change in altitude. As a result, the change in X_{CO_2} only applies to bias-corrected data, and nothing else in the bias correction is changed.

- The standard B10 quality flag is used for all OCO-2 retrievals in this analysis.

Multi-model mean (MMM)

- 10 s swath aggregations of OCO-2 retrievals over land north of 50°N were paired with X_{CO_2} estimates from four models:

1. CarbonTracker CT2019B+NRT2021-3 Andrew Jacobson NOAA
2. Jena Carboscope s10oc-v2021 Christian Rodenbeck MPI-BGC
3. CAMS v20r2 Frederic Chevallier LSCE
4. Univ. of Edinburgh v5 P. Palmer, L. Feng Univ. of Edinburgh

- Pairs of retrievals and model estimates were excluded from the analysis if
  - fewer than 3/4 models are resolved,
  - the model with the maximum difference from the model median differs by more than 1.5 ppm,
  - the standard deviation among model estimates is more than 0.7 ppm.

DEM differences

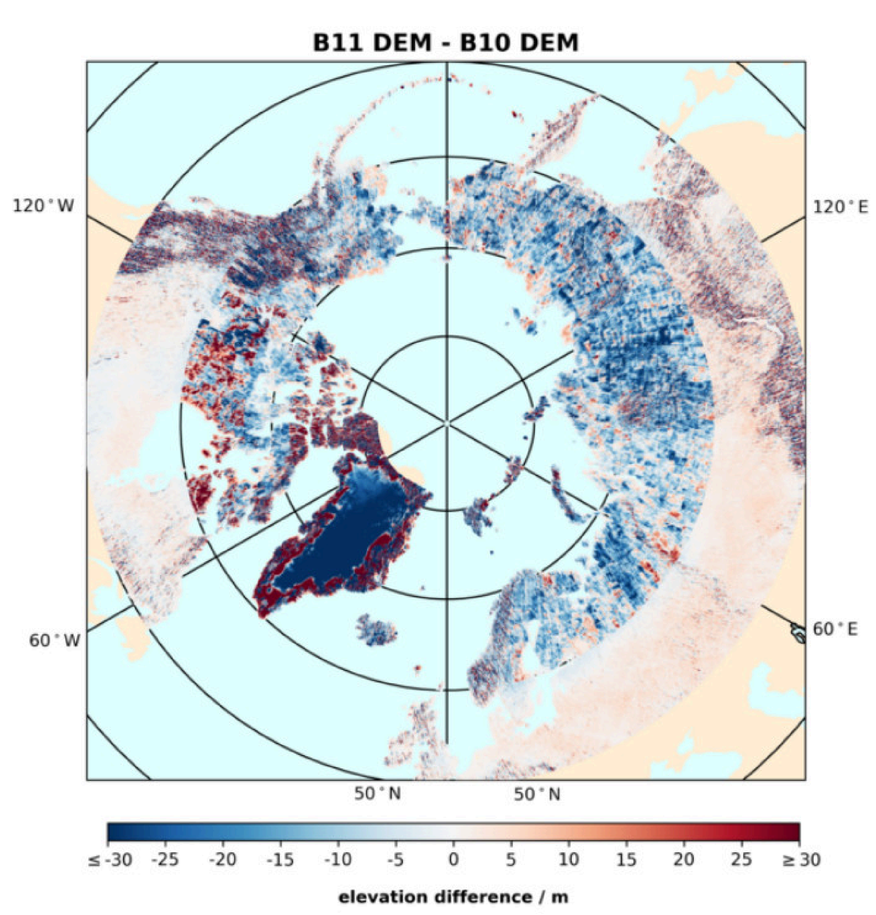

Fig. 1: The difference between the B11 DEM and B10 DEM at with 0.1° aggregation (both include latitudes north of 50°N).

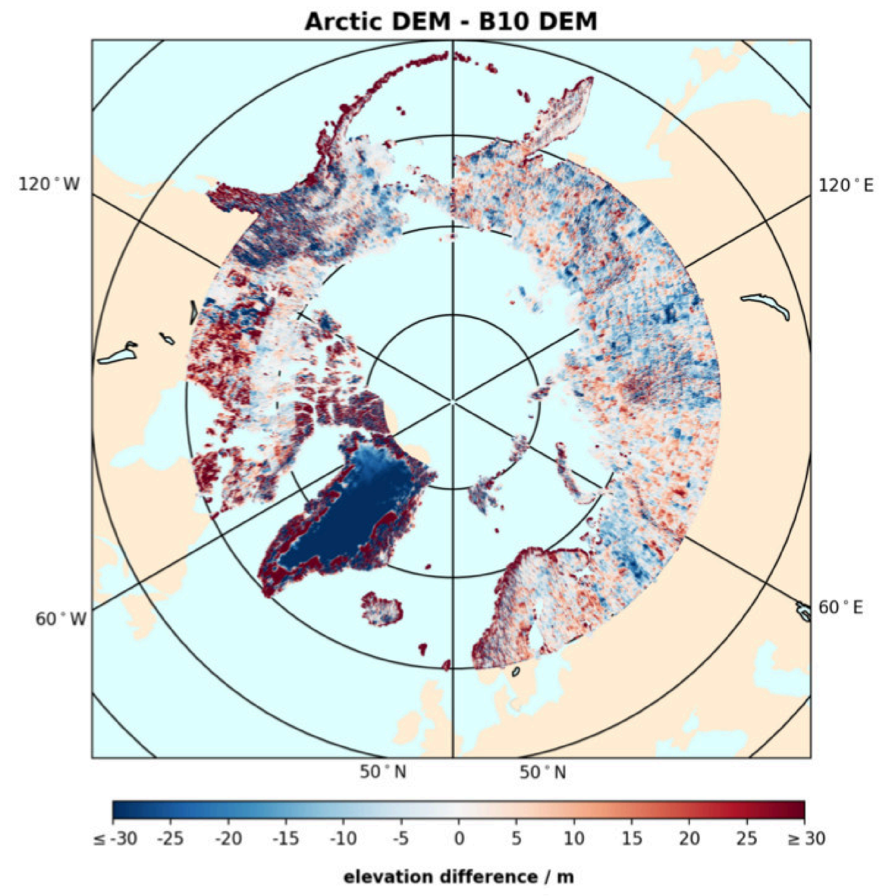

Fig. 2: The difference between the Arctic DEM and B10 DEM at with 0.1° aggregation (the Arctic DEM has very limited coverage south of 60°N).

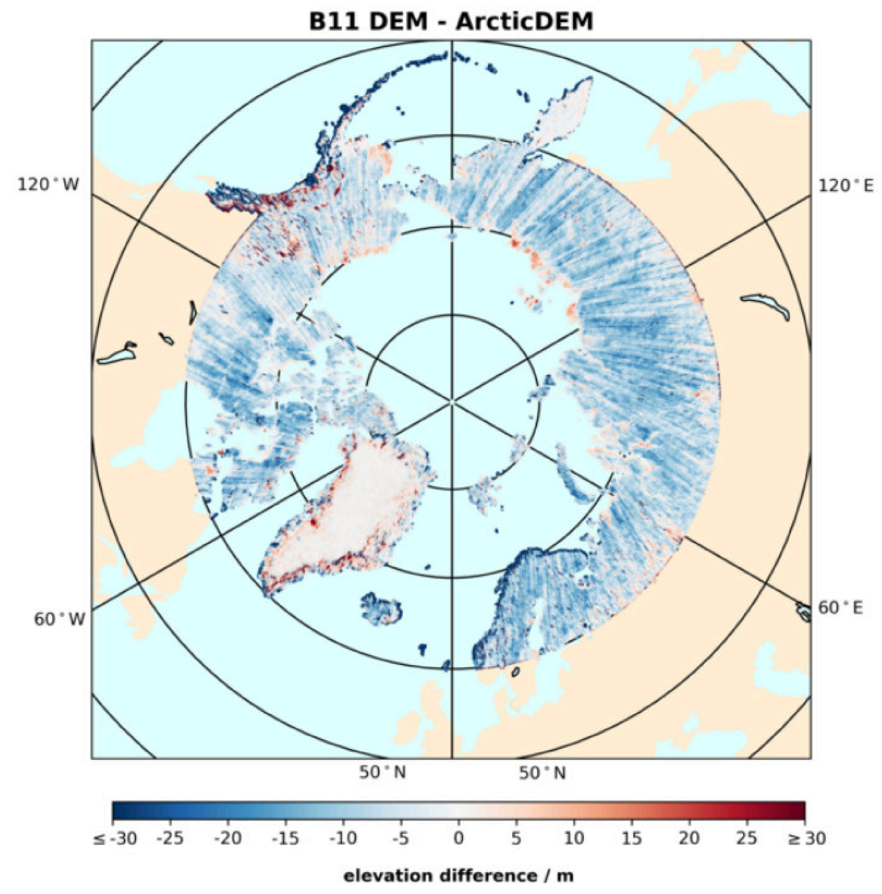

Fig. 3: The difference between the B11 DEM and Arctic DEM at with 0.1° aggregation (the Arctic DEM has very limited coverage south of 60°N).

Changes in X_{CO_2}

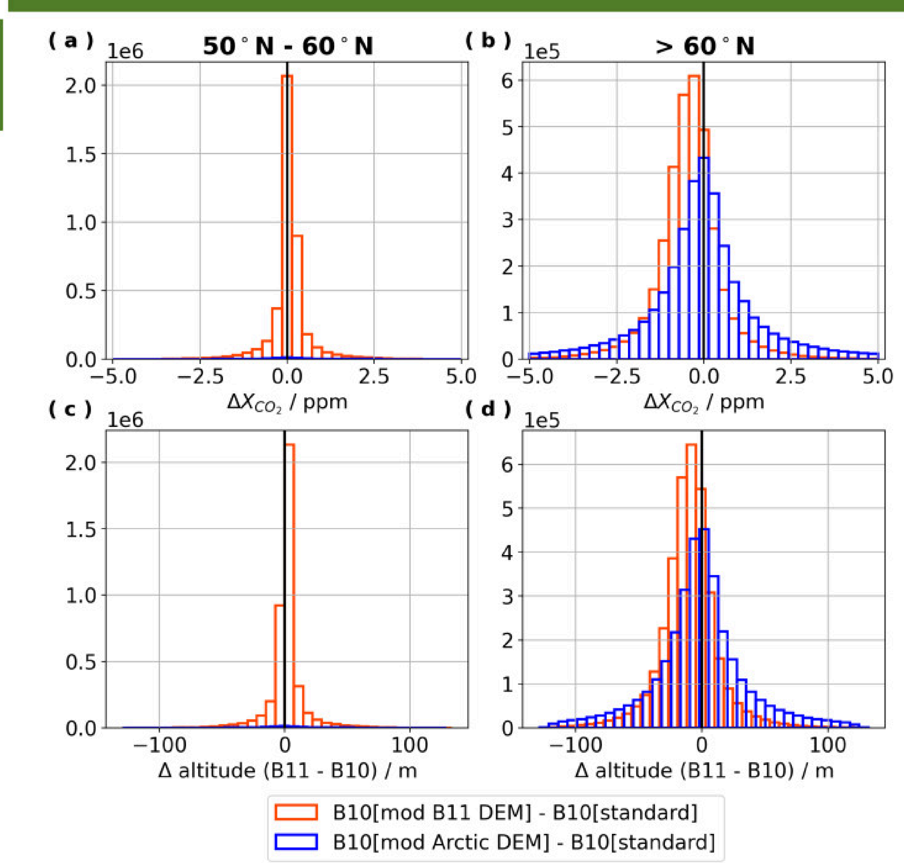

Fig. 4: (a) and (b) show distributions of change in X_{CO_2} from substituting B11 or Arctic DEM in the B10 bias correction for 50°N to 60°N and north of 60°N, respectively. (c) and (d) show the distributions of change in altitude by sounding for 50°N to 60°N and north of 60°N, respectively.

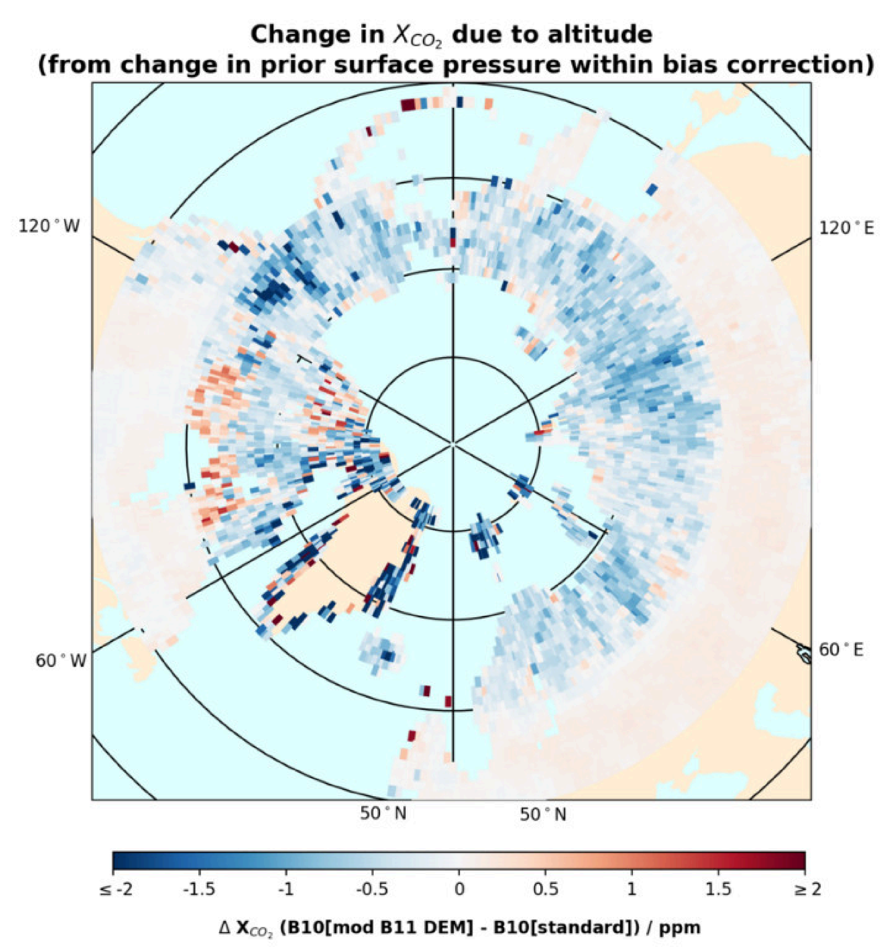

Fig. 5: Map of changes in X_{CO_2} from substituting the B11 DEM in the B10 bias correction, as 1°x1° averages.

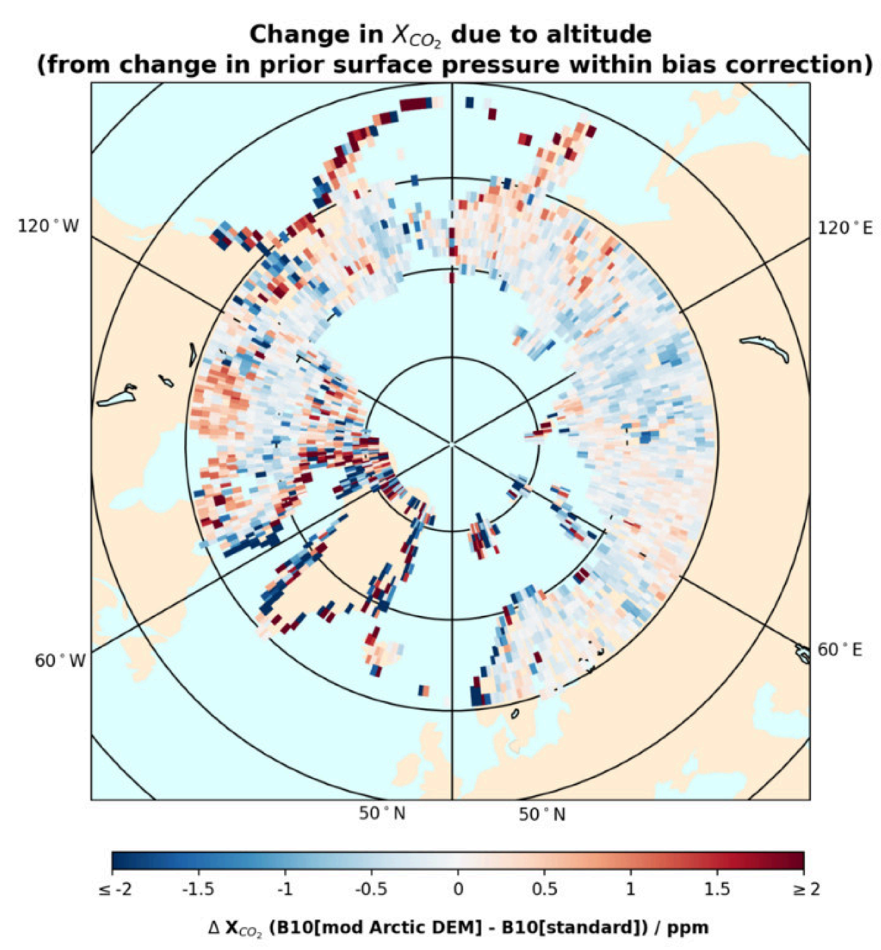

Fig. 6: Map of changes in X_{CO_2} from substituting the Arctic DEM in the B10 bias correction, as 1°x1° averages.

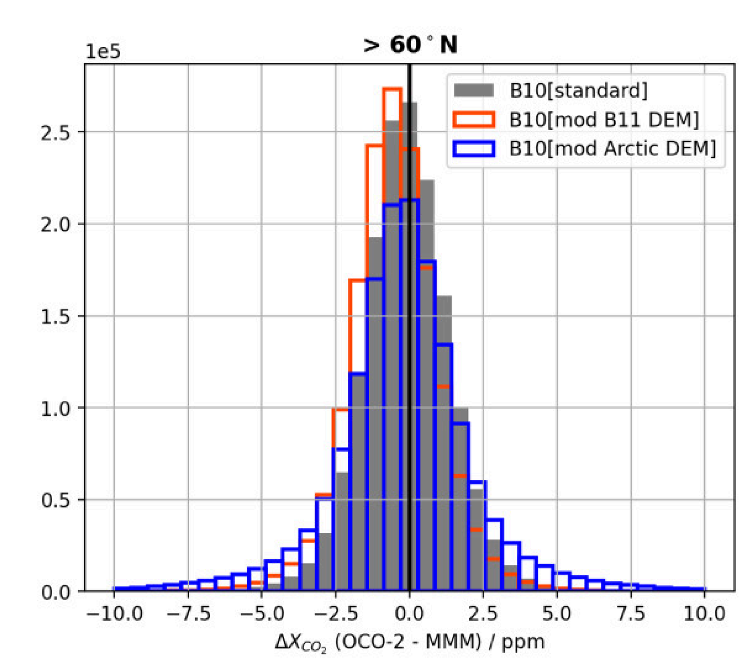

Fig. 7: The distributions of OCO-2 B10 bias relative to the MMM for B10 with the standard bias correction and modified for the B11 and Arctic DEMs.

Table 1: The means and standard deviations of the change in OCO-2 X_{CO_2} and OCO-2 bias relative to MMM for B10 retrievals north of 60°N modified with the B11 DEM and Arctic DEM.

variable (> 60°N)	mean / ppm	standard deviation / ppm
Δ X_{CO_2} (B10[mod B11 DEM] - B10[standard])	-0.424	1.01
Δ X_{CO_2} (B10[mod Arctic DEM] - B10[standard])	-0.075	2.29
Δ X_{CO_2} (B10[standard] - MMM)	-0.099	1.51
Δ X_{CO_2} (B10[mod B11 DEM] - MMM)	-0.527	1.56
Δ X_{CO_2} (B10[mod Arctic DEM] - MMM)	-0.196	2.60

- For calculations of change in X_{CO_2} with the Arctic DEM, sounding latitude and longitude are paired with 0.1°x0.1° aggregations, while for the B11 DEM a 0.01°x0.01° grid is used. This may explain the higher variance when substituting the Arctic DEM.
- A direct mapping to the sounding footprint would be the best method, but takes time.

Conclusions and future work

- For soundings north of 60°N the B11 DEM yields a larger negative shift in X_{CO_2} relative to the standard B10 than the Arctic DEM.
- The negative shift in OCO-2 retrieved X_{CO_2} with the B11 DEM also yields a more negative average bias in OCO-2 relative to the MMM.
- It should be noted that a bias correction appropriately tailored to a specific DEM may yield better statistics than simply changing the dpfrac value without calculating a new bias correction. Later, we plan to consider a new B10 bias correction for northern high latitudes that includes a modified dpfrac term.
- Next, we will include the Copernicus 30 m DEM in these comparisons, and test DEM self-consistency across the 60°N parallel.
- The DEMs will also be mapped directly to sounding footprints for a more accurate assessment of the effects of different DEMs on X_{CO_2}.

Acknowledgments

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References

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