Using Deep Convective Clouds to Characterize Relative Radiometric Bias in Shortwave Spectrometers

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Deep Convective Clouds (DCC)

DCCs are useful relative radiometric calibration targets for shortwave sensors, as they act as spatially uniform reflective surface above spatially heterogenous constituents (water vapor, aerosols) in Earth's atmosphere. Generally, DCC can be identified by cold cloud temperatures detected in the mid-IR window. **Fig. 1** shows DCCs in MODIS imagery from NASA Worldview.

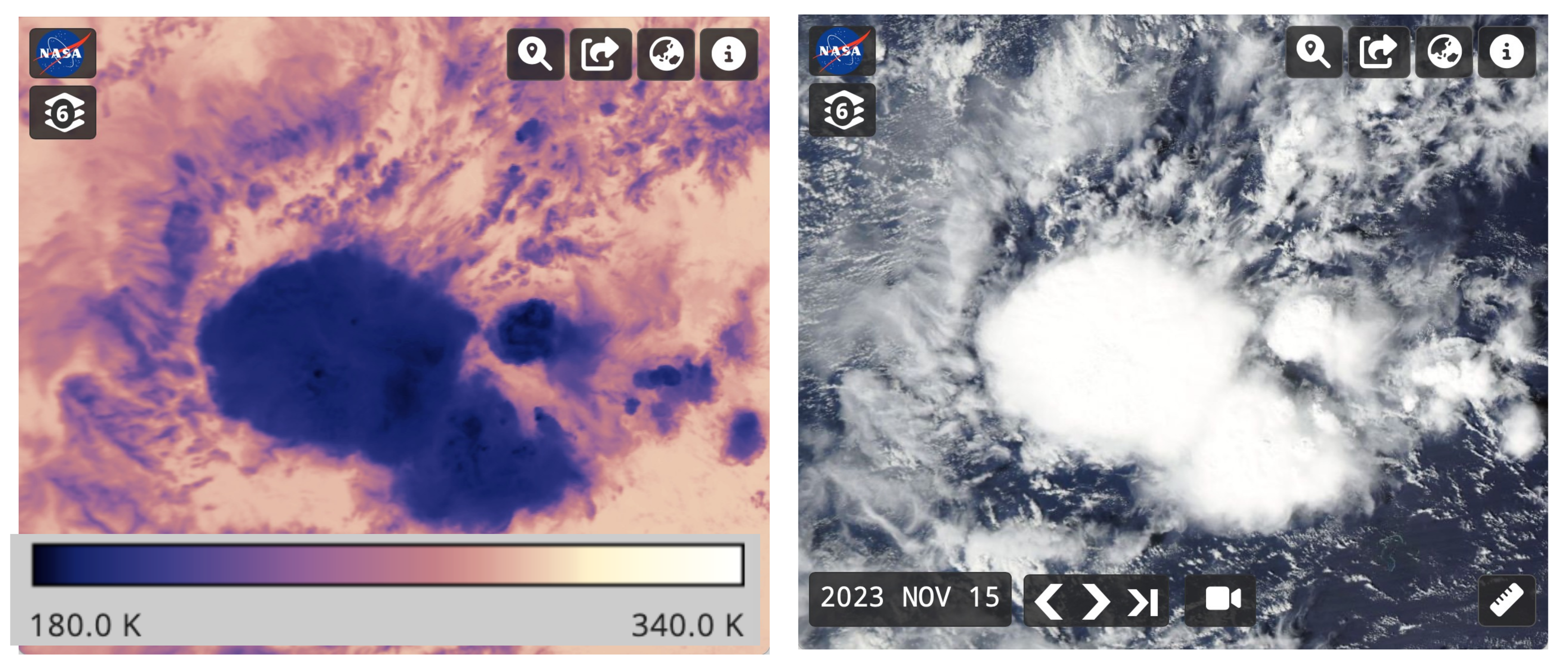

Figure 1: MODIS imagery of DCCs; IR window (Left) and true color (Right)

DCCs have been successfully used to characterize relative radiometric biases in many spectral radiometers that contain detector arrays.
In MODIS data, DCCs are identified primarily with a cutoff in IR window brightness temperature (< 205 K). Additional filters ensure spatial homogeneity and limit the solar zenith angle (< 40 degrees) (Chang 2016)

DCC identification in Shortwave spectrometers

We require a method to identify DCC directly from shortwave data.
In other words, we cannot rely on IR window radiance.
Instead, DOAS retrievals can be used, as the partial gas column will be related to the cloud top altitude

Proof of concept with NASA Orbiting Carbon Observatory-2:

The IMAP-DOAS Preprocessor (IDP) runs on all observations. Used for cloud screening.

The DOAS CO2 column retrieval from the Weak CO_2 (WCO2) band at 1.6 μm is the most useful for identifying DCC.

The CO_2 column ratio (retrieved / prior) is roughly proportional to the cloud top pressure.

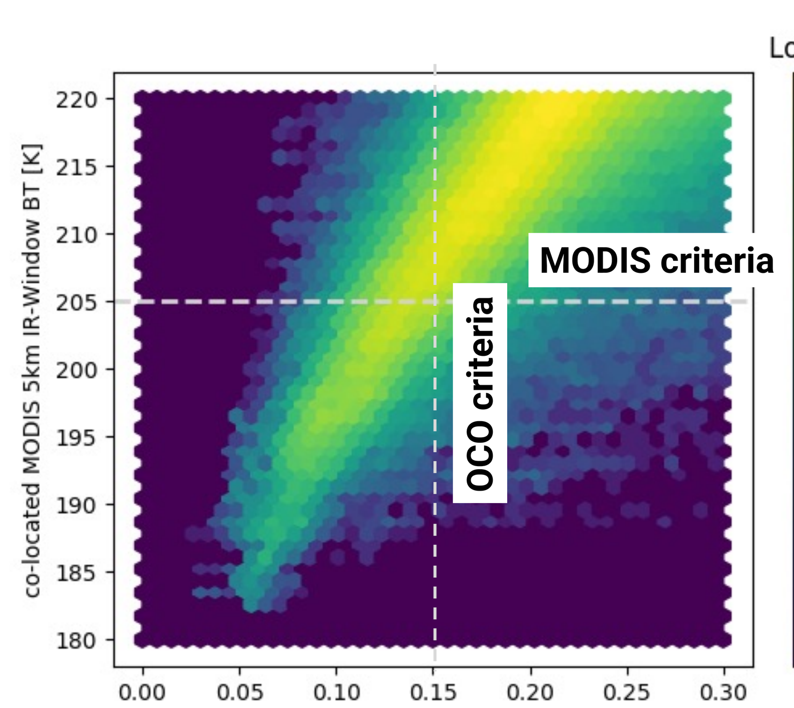

Fig. 2: MODIS IR BT vs OCO-2 IDP ratio

selecting OCO observations with IDP WCO2 ratio < 0.15 is equivalent to the MODIS DCC selection criteria (Mid-IR Window BT < 205 K)

DCC in co-located MODIS & OCO-2 data

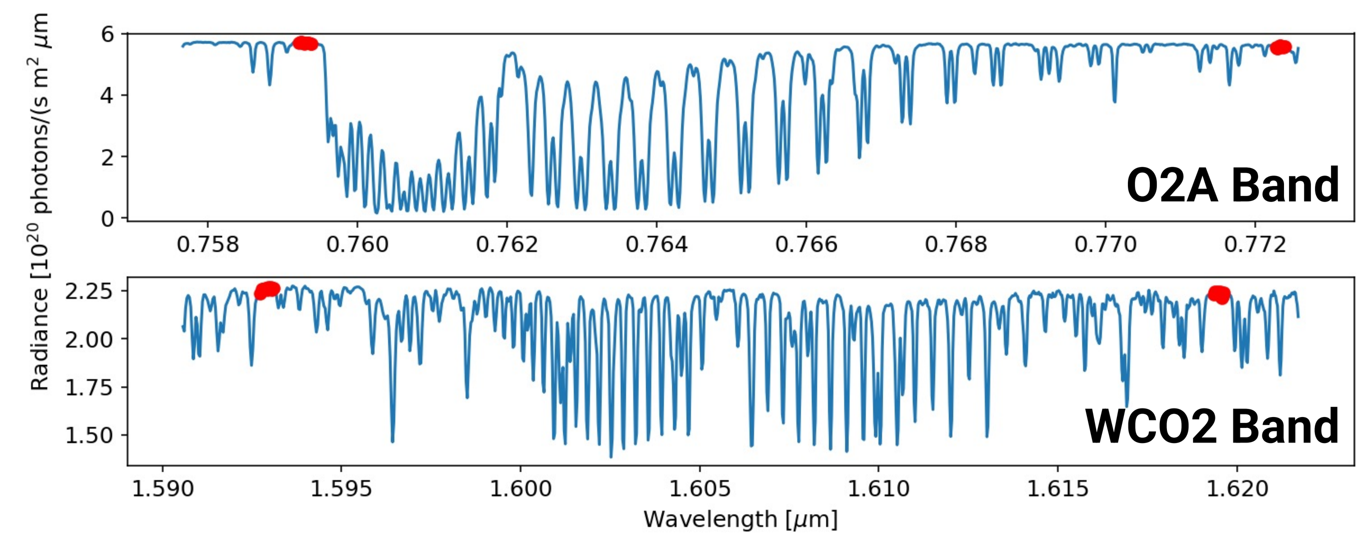

Figure 3: Sample OCO-2 spectra, with continua marked (Red dots)

Continuum radiances are extracted from OCO-2 spectra by selecting wavelength samples outside of absorption lines (**Figure 3**). SCO2 band is omitted, due to lack of suitable continuum samples.

Figure 4 shows the reflectance distribution of OCO-2 O2A continuum radiance, selected either using the IDP WCO2 or MODIS IR BT (obtained through OCO-2 and MODIS-Aqua co-location). The close match shows equivalence between the two selection methods.

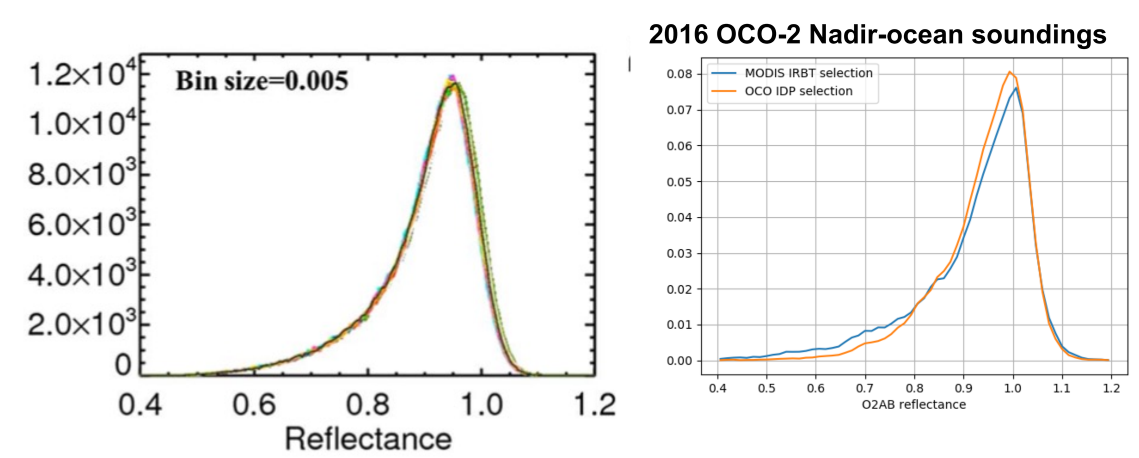

Figure 4: DCC Reflectance PDF from MODIS bands (Chang 2016), compared to PDF of OCO-derived O2A band DCC continua reflectance.

DCC selections in OCO-2 and OCO-3

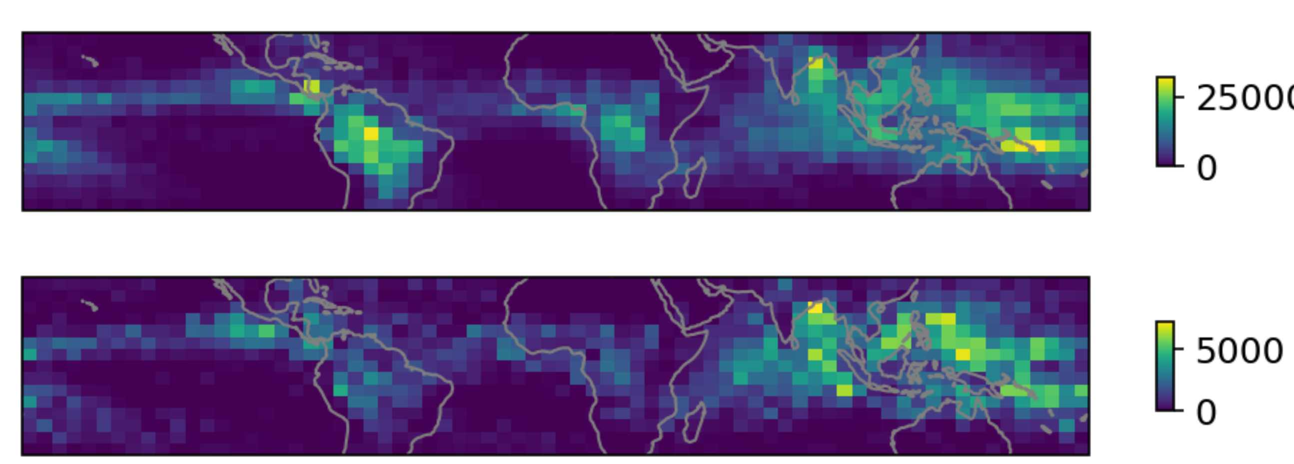

Figure 5: DCC Locations OCO-2 (top) OCO-3 (bottom)

DCCs are detected in the expected tropical regions (Fig. 5) and the distribution over time is approximately constant (Fig. 6)

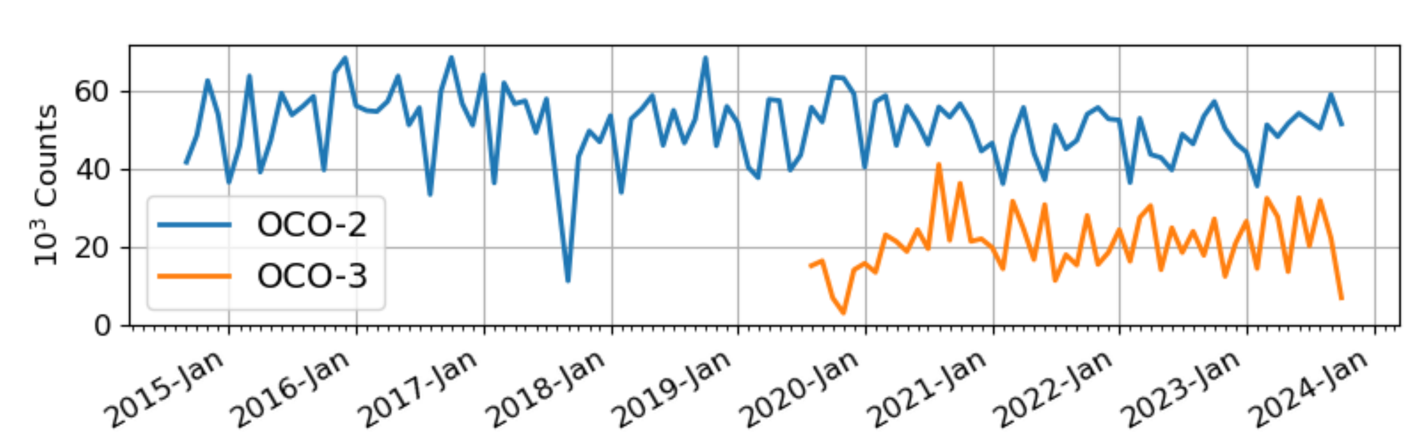

Figure 6: Counts of DCC obs over all modes for OCO-2 and -3.

Results and Implications for OCO-2/3

OCO-2 has a mature radiometric model after 9 years of operation. Inter-footprint radiometric biases are very small (Fig. 7) and the results here validate the "streak flat" approach for characterizing inter-footprint bias ("Streak-flats" are data collections where each spatial footprint follows the same ground track).
No temporal trends were noted in the DCC relative radiance over the OCO-2 data record.(not shown).

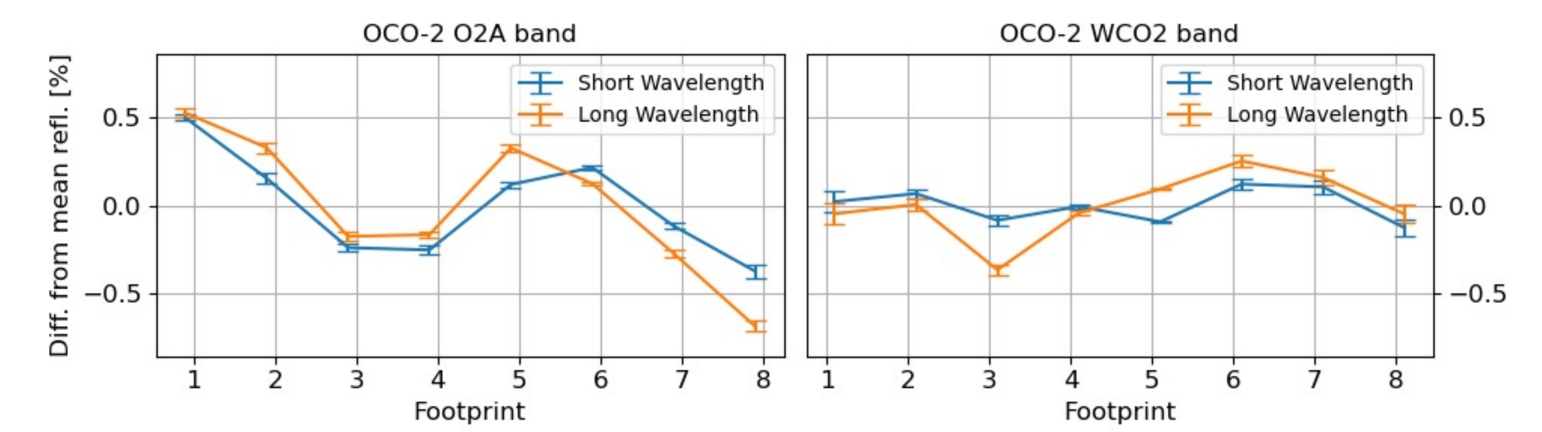

Figure 7: Relative radiometric offsets for OCO-2 O2A (L) and WCO2 (R) from DCC observations. Inter-footprint biases are less than 0.75%. Error bars are the stdev. of estimates computed in each of 4 data groups (Glint/Nadir, Land/Ocean)

OCO-3 cannot collect "streak flat" data, so the Radiometric offsets determined by DCC analysis are needed to derive inter-footprint radiometric corrections. Analysis of the OCO-3 data record is ongoing.

Conclusions

This analysis uses fast non-scattering IMAP-DOAS retrievals that are used for cloud screening but not for CO_2 retrieval as the accuracy is generally too low. ***The same general technique can be applied to other similar trace gas remote sensors to characterize relative radiometric biases across detector arrays and over time.***

For SWIR bands (λ > 1.3 μm), angular dependence of DCC reflectance increases (BRDF effects, see Fig 8)

Comparisons across time, or comparisons with wide-swath instruments may need to take BRDF effects into account for the best precision.

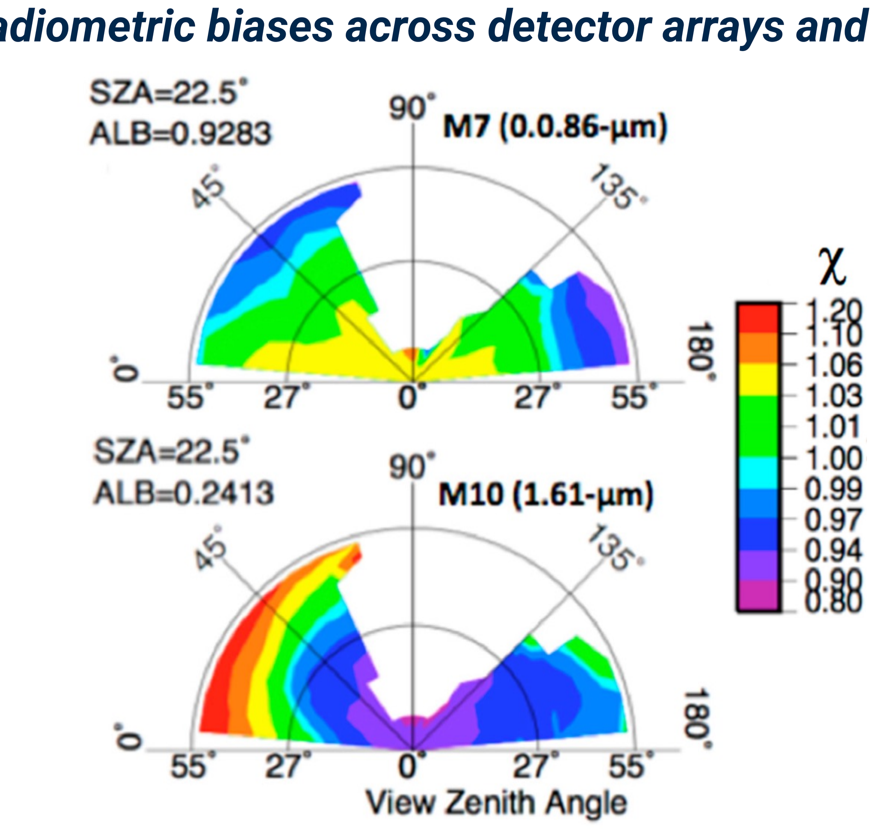

Figure 8: Empirical DCC BRDFs estimated from VIIRS data, showing increased variation at 1.6 μm vs 0.86 μm. From Bhatt 2017, Fig. 4.

References:

Chang 2016 JGR-A. DOI:10.1002/2015JD024652
Bhatt 2017 Remote Sensing DOI:10.3390/rs9101061
NASA Earthdata data product DOIs:
OCO-2 V11r L1b: 10.5067/H93644NLXWX9 L2IDP: 10.5067/MKXMQPRVMGW0
OCO-3 V10r L1b: 10.5067/G9F1X13ZY0Y8 L2IDP: 10.5067/TY9NJALFN9K5