Emissions, Topography, and Variation in X_{CO2} above the Southern California Megacity

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Introduction

The South Coast Air Basin (SCB) is home to 17 million people sprawled over more than 160 cities. About half a percent of global anthropogenic carbon emissions come from here. The SCB is a focus site for carbon emission studies using both in situ and remote sensing measurements. Because of the sharp topographic relief, and valleys that cut through the basin the terrain is unique and the circulation is complex.

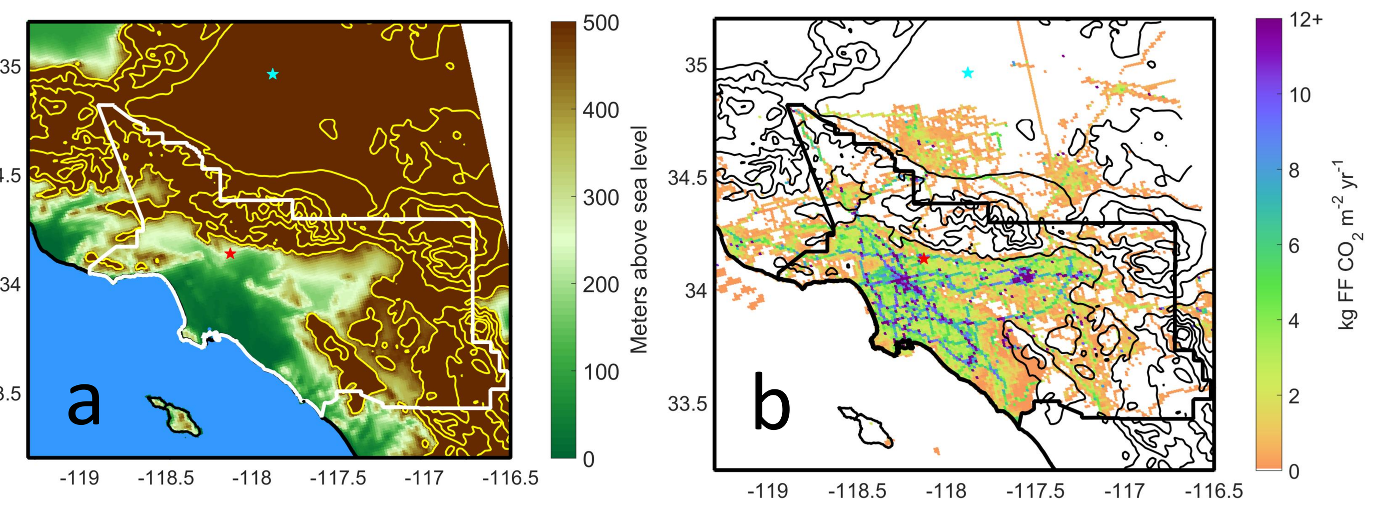


Figure 1. a. Topography of SCB, defined by white line. Caltech TCCON site is at red star. Armstrong TCCON site is at cyan star in the desert. Yellow lines are topographical lines every 500 m. **b.** Hestia-LA fossil fuel (FF) CO_2 emissions average for 2012. Purple area SW of Caltech is downtown Los Angeles (LA).

Datasets

I. TCCON

Total Carbon Column Observing Network[1] (TCCON) data are column averaged dry air mole fractions of various gases (X_{gas}), including X_{CO2} and X_{CH4}, measured by ground-based solar viewing spectrometers. Sites used were California Institute of Technology[2] (Caltech), Jet Propulsion Laboratory[3] (JPL) 8 km NNW of and 150 m higher than Caltech, and NASA Dryden/Armstrong Flight Research Center[4] (AFRC) 95 km north of Caltech. Differences are presented in **Figures 2 & 3**.

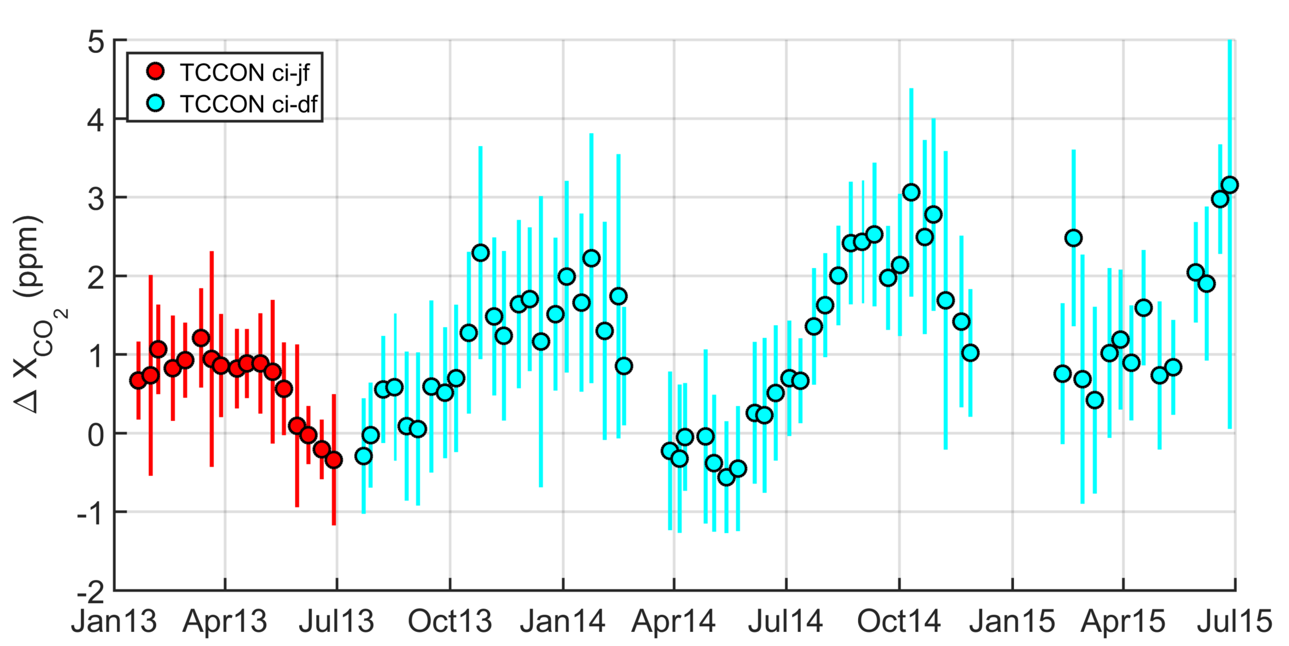


Figure 2. Full time series of differences in X_{CO2} at Caltech (ci) compared with another AFRC (df) or JPL (jf) site. Differences are 10 day binned hourly differences. Bars are 1σ spreads.

II. Hestia–LA with WRF simulation

The Hestia-LA dataset quantifies fossil fuel CO_2 emissions at the scale of buildings[5] based off of 2010–12 emissions. We coupled this with a 1.3 × 1.3 km (50 layer) Weather Research and Forecasting Model (WRF) simulation over January–April 2015. In regards to WRF, SCB is the mean X_{CO2} over the entire basin, $\overline{X_{CO2}}$.

III. OCO-2

The Orbiting Carbon Observatory-2 (OCO-2) satellite makes measurements of X_{CO2} at a resolution of ~1.3 × ~2.25 km over 8 longitudinal footprints. It passes over the SCB at around 21 UTC. The data set[6,7] began in Sept 2014.

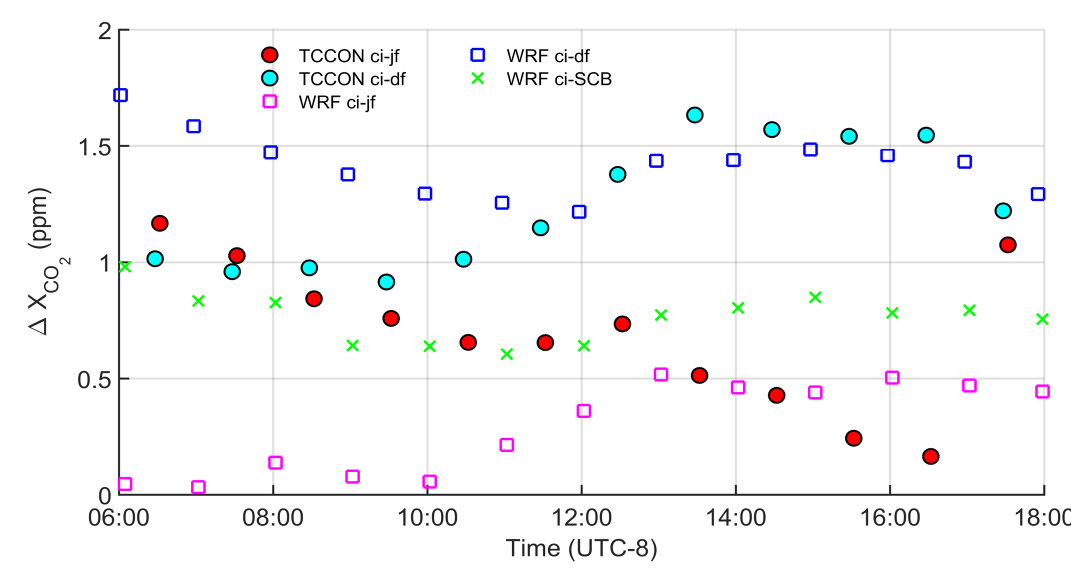


Figure 3. Diurnal differences in X_{CO2} at Caltech compared with AFRC, JPL or mean SCB X_{CO2}. 1σ spreads were 0.7, 1.4, 0.6, 1.2, and 0.9 ppm for TCCON ci-jf, ci-df and simulated ci-jf, ci-df, and ci-SCB respectively. Trends with X_{CH4} are similar with 0.25% ci-jf differences at 21 UTC. The TCCON ci-df at 21 UTC of 1.6 ppm is likely smaller than that calculated from GOSAT[8] of 3.2 ± 1.5 ppm (1σ), because of the difference in where basin measurements were made.

Discussion

a. X_{CO2} & terrain relationship

Although the typical 0.7 ppm gradient at 13:00 (UTC-8) between Caltech and JPL may be explained by a combination of dynamics, CO_2 emissions, and uptake we consider a fourth factor—topography. If mixed layer (ML) height pressure p_{ML}, and average CO_2 above $(\langle[CO_2]\rangle_{abv})$ and within the ML $(\langle[CO_2]\rangle_{ML})$ are the same at two sites then X_{CO2} should relate with surface pressure p as

$$X_{CO_2} = \frac{1}{p}\left(p_{ML} \times \left(\langle[CO_2]\rangle_{abv} - \langle[CO_2]\rangle_{ML}\right)\right) + \langle[CO_2]\rangle_{ML} \quad \textbf{Eq. 1}$$

We evaluate this in the simulations over small areas using the coefficient of determination (R^2) with the sign of the slope. **Figure 4** shows an example.

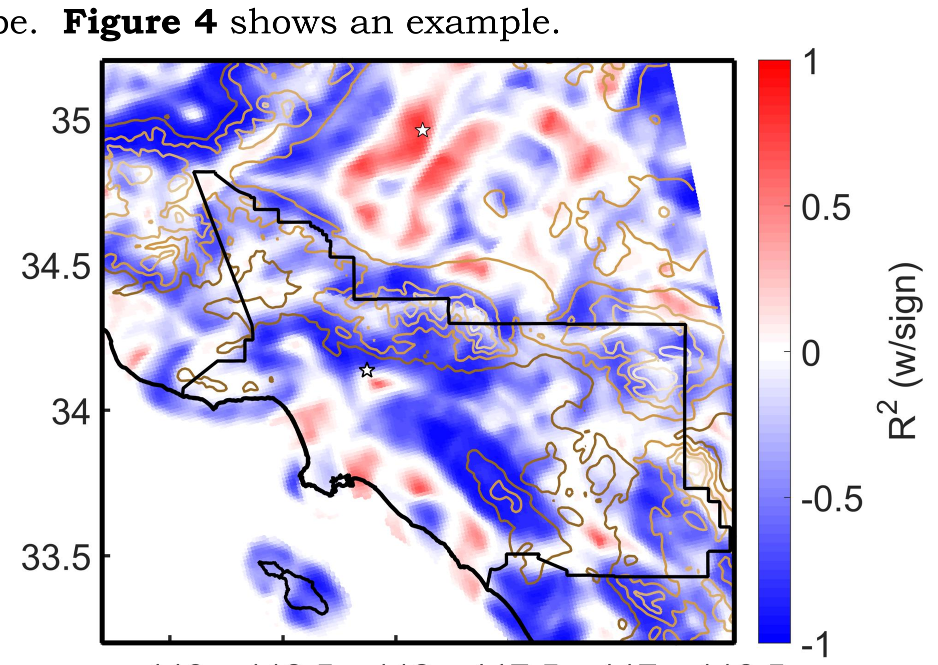


Figure 4. R^2 with sign of slope for the eq. 1 relationship over areas with radii of 9.1 km on March 9, 2015, 21 UTC. See also **Figure 6b.**

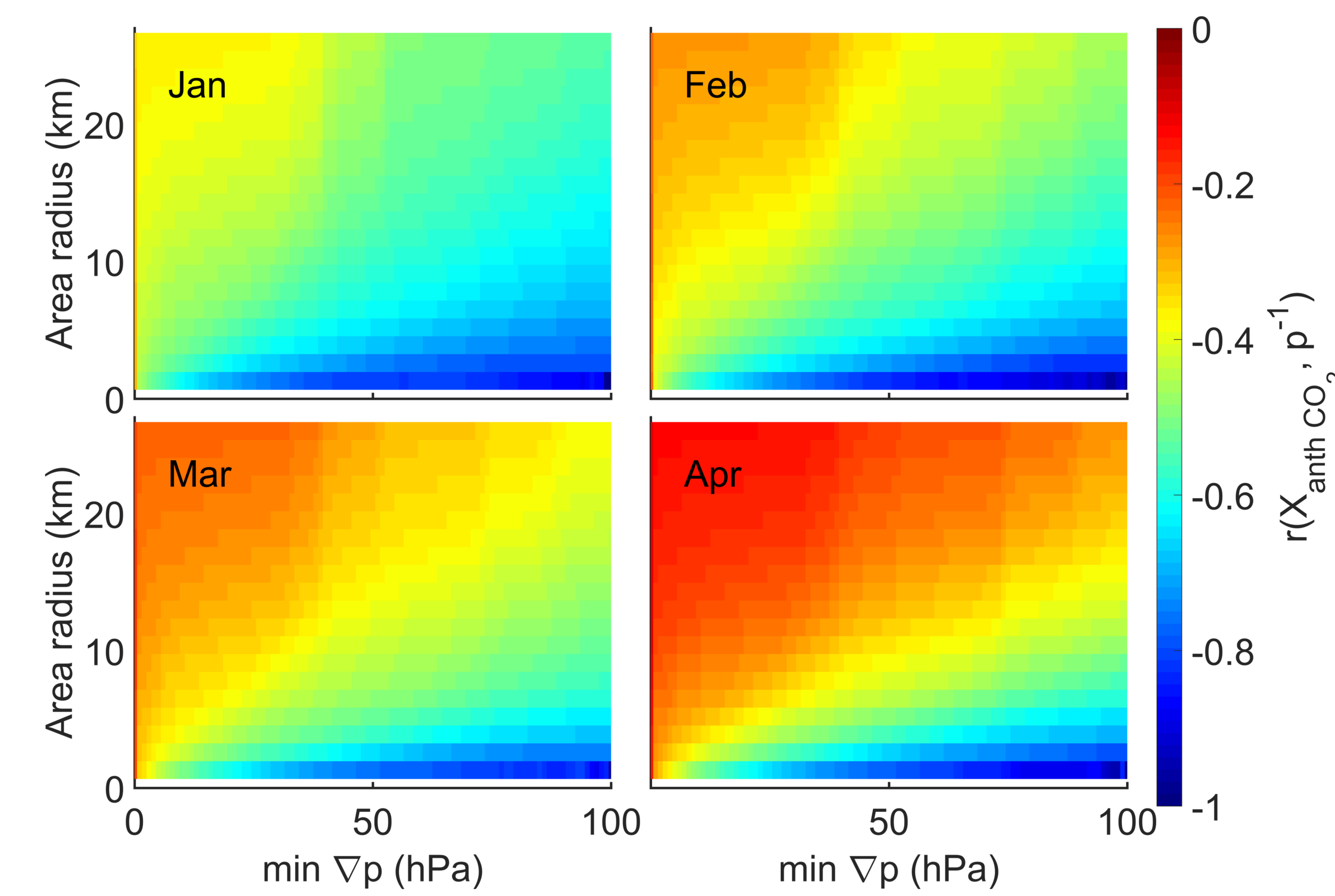
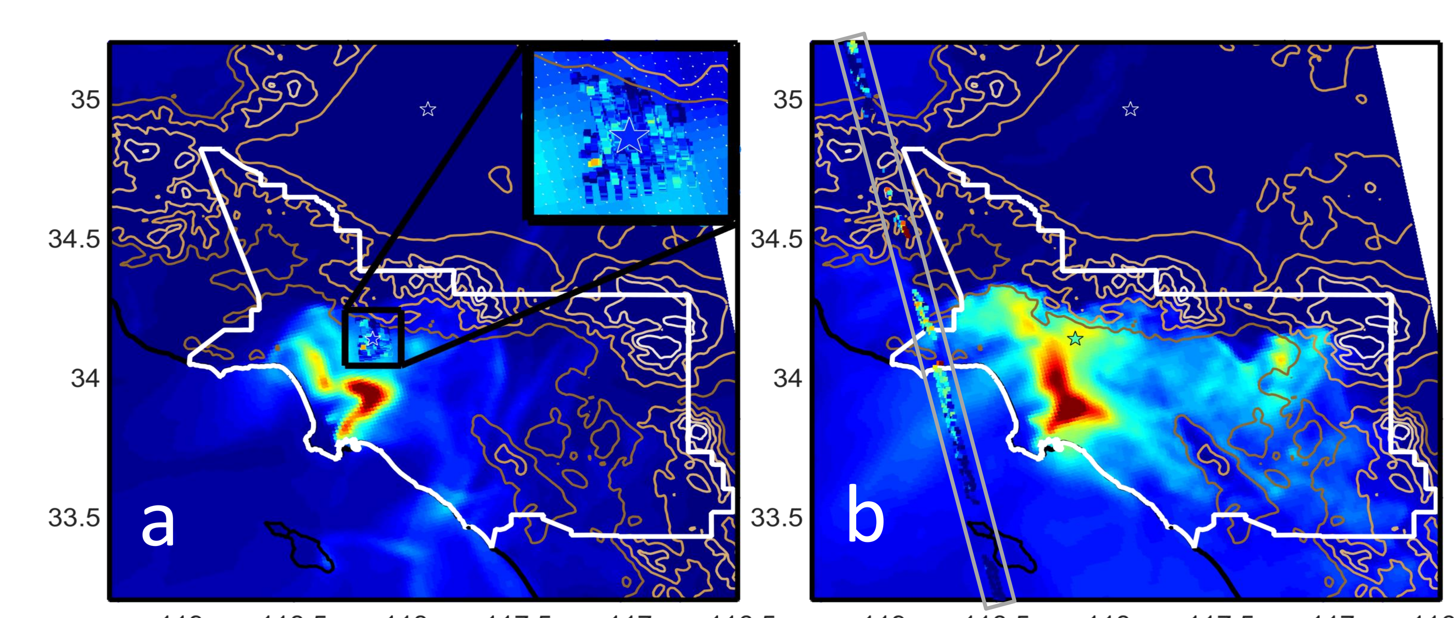


Figure 5. Average correlation coefficients (r) in small areas for equation 1 over SCB simulations considering different area radii, minimum pressure gradients ∇p, and months. In general smaller areas and larger gradients have a stronger relationship. The relationship becomes weaker towards April possibly due to a less stable ML.

b. Qualitative comparison

We make a preliminary comparison of the 3 datasets; averaging kernels were not taken into account. OCO-2 and the simulation both capture large (~20 km wide) plumes e.g. off the coast in **Figure 6b**.



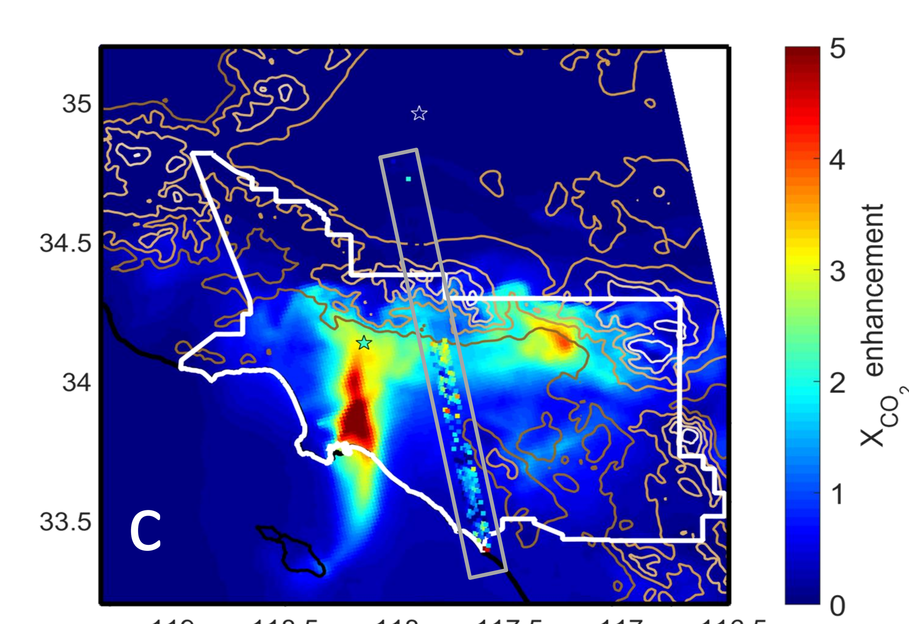


Figure 6. OCO-2 & Caltech TCCON X_{CO2} overlaid on WRF Hestia-LA simulation at 21 UTC. AFRC X_{CO2} was used as background so those stars are empty. **a.** OCO-2 target mode Mar. 7, 2015, warn levels (WL)<11. **b.** Glint mode Mar. 9, 2015, WL<20. OCO-2 track is highlighted in the gray rectangle. **c.** Nadir mode Apr 1, 2015, WL<12.

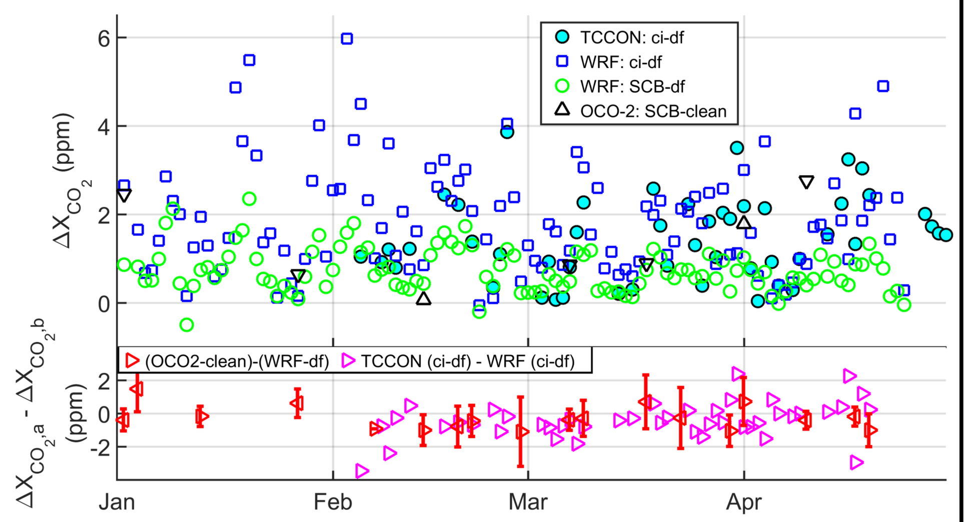


Figure 7. Delta enhancements of basin compared to "clean" air in 2015. Clean measurements were from the AFRC TCCON or for OCO-2 could be a different part of the track (ocean or desert +1 ppm). An interpolated TCCON product as background is denoted by opposite-pointing triangles. OCO-2 data with wl<12 were used.

Higher scatter from individual WRF points compared to $\overline{X_{CO2}}$ suggests a measured $\overline{X_{CO2}}$ (e.g. by the planned OCO-3) would have less day to day variability than a single site.

c. Single site & full SCB $\overline{X_{CO2}}$ covariation

SCB $\overline{X_{CO2}}$ minus AFRC, compared with just Caltech data are in **Table 1**. The strong relationship between ci-df X_{CO2} and $\overline{X_{CO2}}$ -df, supports the notion that percent changes in X_{CO2} taken over a small area could reflect basin-wide changes.[8]

Table 1. Relationship between Caltech and entire basin.

	ci-df (X_{CO2}) vs. SCB-df	R^2	Caltech ~50 magl[a] vs. SCB-df	R^2
21 UTC	$0.39x + 0.07$	0.71	$0.015x + 0.29$	0.47
All times	$0.34x + 0.28$	0.60	$0.0075x + 0.34$	0.19

[a]magl=meters above ground level, single level. Here x is the difference between $\overline{X_{CO2}}$ and X_{CO2} at AFRC.

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Acknowledgements

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