Characterization of OCO-2 biases and errors for flux estimates

Susan S. Kulawik[1]

OCO-2: Christopher O'Dell, Greg Osterman

TCCON: Paul Wennberg, Debra Wunch, Coleen Roehl, Nicholas Deutscher, Matthäus Kiel, David Griffith, Voltaire Velazco, Justus Notholt, Thorsten Warneke, Christof Petri, Martine De Maziere, Mahesh Kumar Sha, Sussmann, Ralf,Rettinger, Markus, Dave Pollard, Isamu Morino, Osamu Uchino, Frank Hase, Dietrich Feist, Kimberly Strong, Rigel Kivi, Laura Iraci, Kawakami Shuji, Manvendra Dubey, Eliezer Sepulveda, Omaira Elena Garcia Rodriguez, Yao Te, Pascal Jeseck, Matt Kiel, Pauli Heikkinen, Matthias Schneider

ATom: Steve Wofsy, Kathryn McKain, Colm Sweeney

OCO-2 average products: David Baker, Junjie Liu

Estimating biases and errors of CO_2 from satellites and models

Carryover funding from 4-year NASA ESDR project to characterize satellite CO_2

Goals of our project

- Apply rigorous methodology to unify space-based CO_2 observations
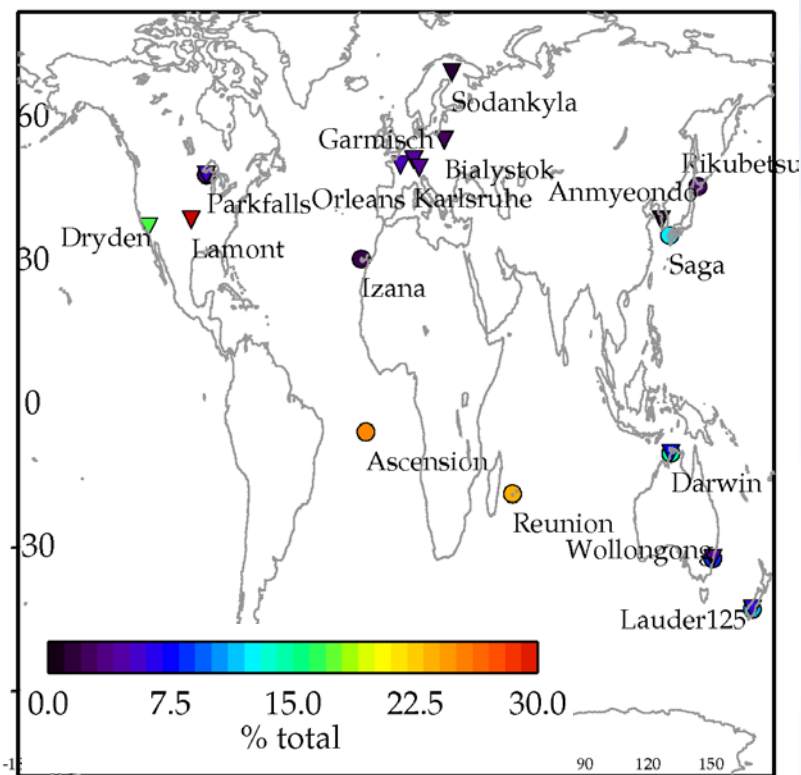
Goals of this work

- Errors for single observation OCO-2 (v8) and ACO2-GOSAT (v7.3)
- How errors reduce with averaging
- OCO-2 biases
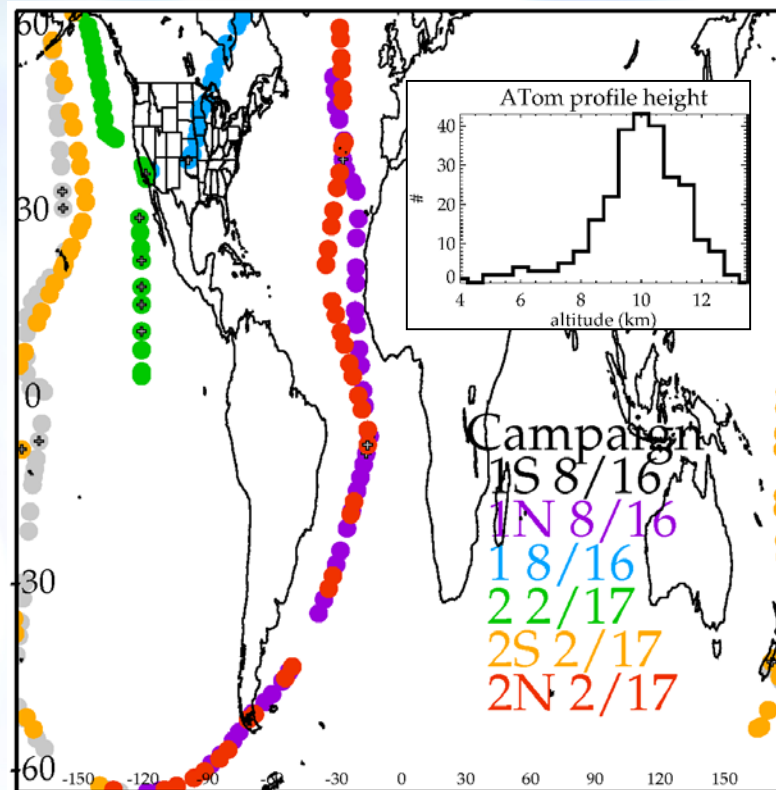 - Spatial and temporal correlation lengths of biases
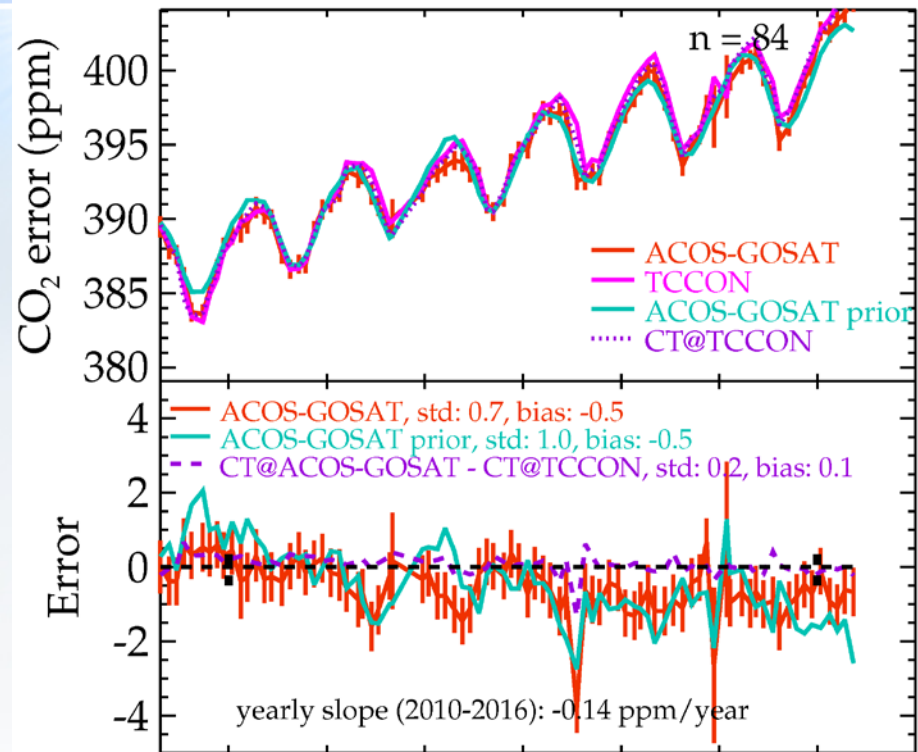
TCCON and ATom

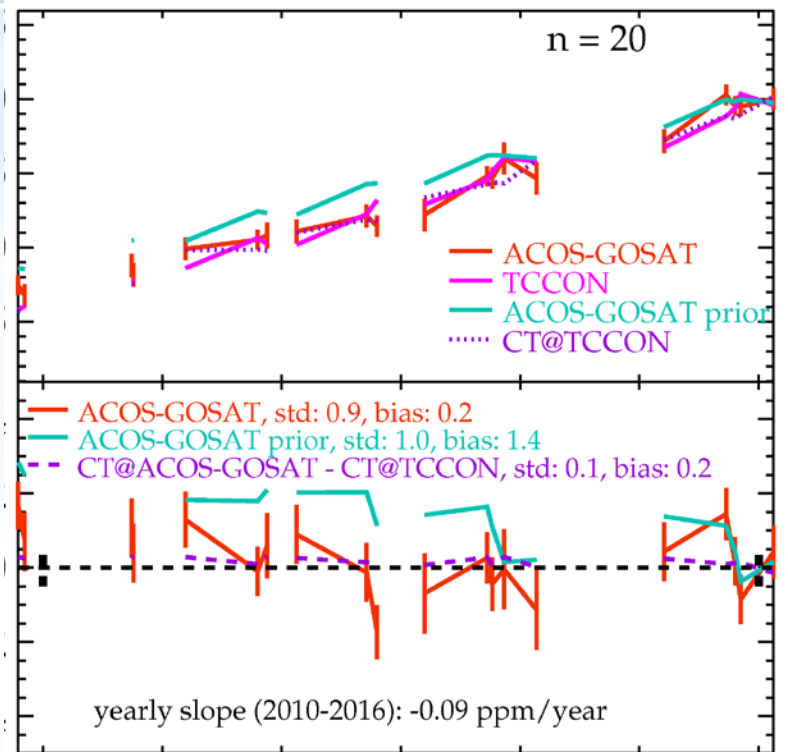TCCON sites: XCO_2

ATom measurements: CO_2 profile
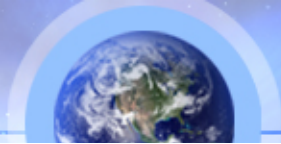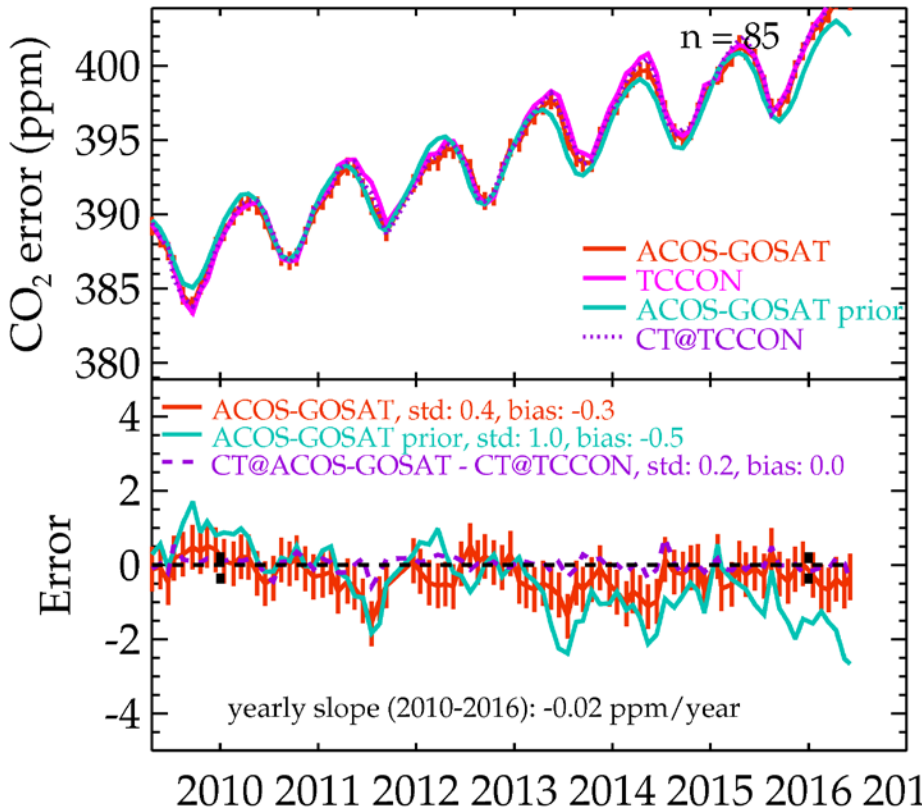
Geometric Coincidence
±3 degrees latitude
±5 degrees longitude
±1 hour

Susan Kulawik 5/2018   4

ACOS-GOSAT v7.3

TCCON Lamont

n = 85

ACOS-GOSAT
TCCON
ACOS-GOSAT prior
CT@TCCON

ACOS-GOSAT, std: 0.4, bias: -0.3
ACOS-GOSAT prior, std: 1.0, bias: -0.5
CT@ACOS-GOSAT - CT@TCCON, std: 0.2, bias: 0.0

yearly slope (2010-2016): -0.02 ppm/year

TCCON Darwin

n = 66

ACOS-GOSAT
TCCON
ACOS-GOSAT prior
CT@TCCON

ACOS-GOSAT, std: 0.7, bias: 0.0
ACOS-GOSAT prior, std: 1.0, bias: 1.3
CT@ACOS-GOSAT - CT@TCCON, std: 0.3, bias: 0.0

yearly slope (2010-2016): -0.02 ppm/year

Dynamic Coincidence
± 5 days

$$\left(\left(\frac{\Delta Latitude}{10}\right)^2 + \left(\frac{\Delta Longitude}{30}\right)^2 + \left(\frac{\Delta Temperature}{2}\right)^2\right) < 1$$

Susan Kulawik 5/2018   5
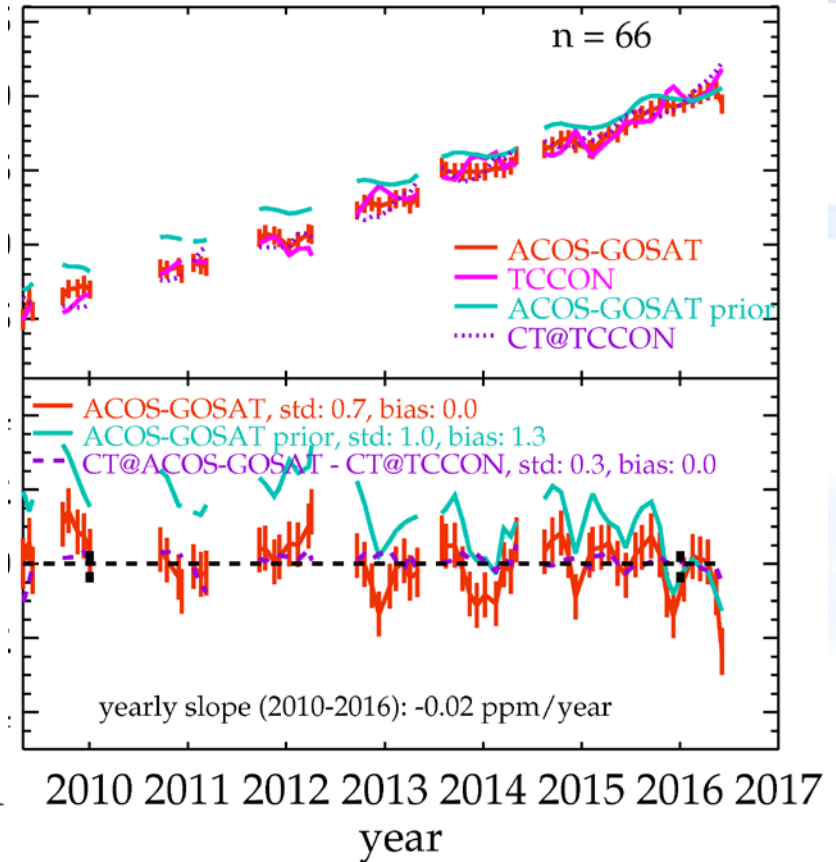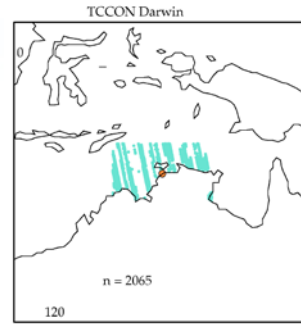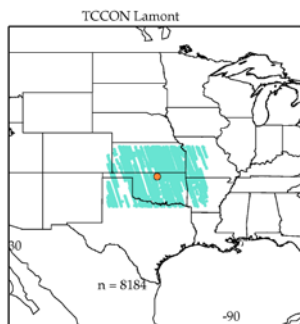
Geometric Coincidence
±3 degrees latitude
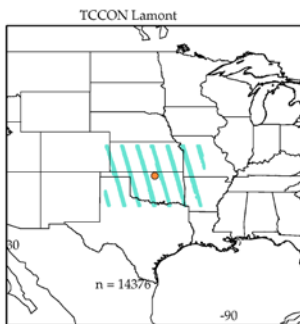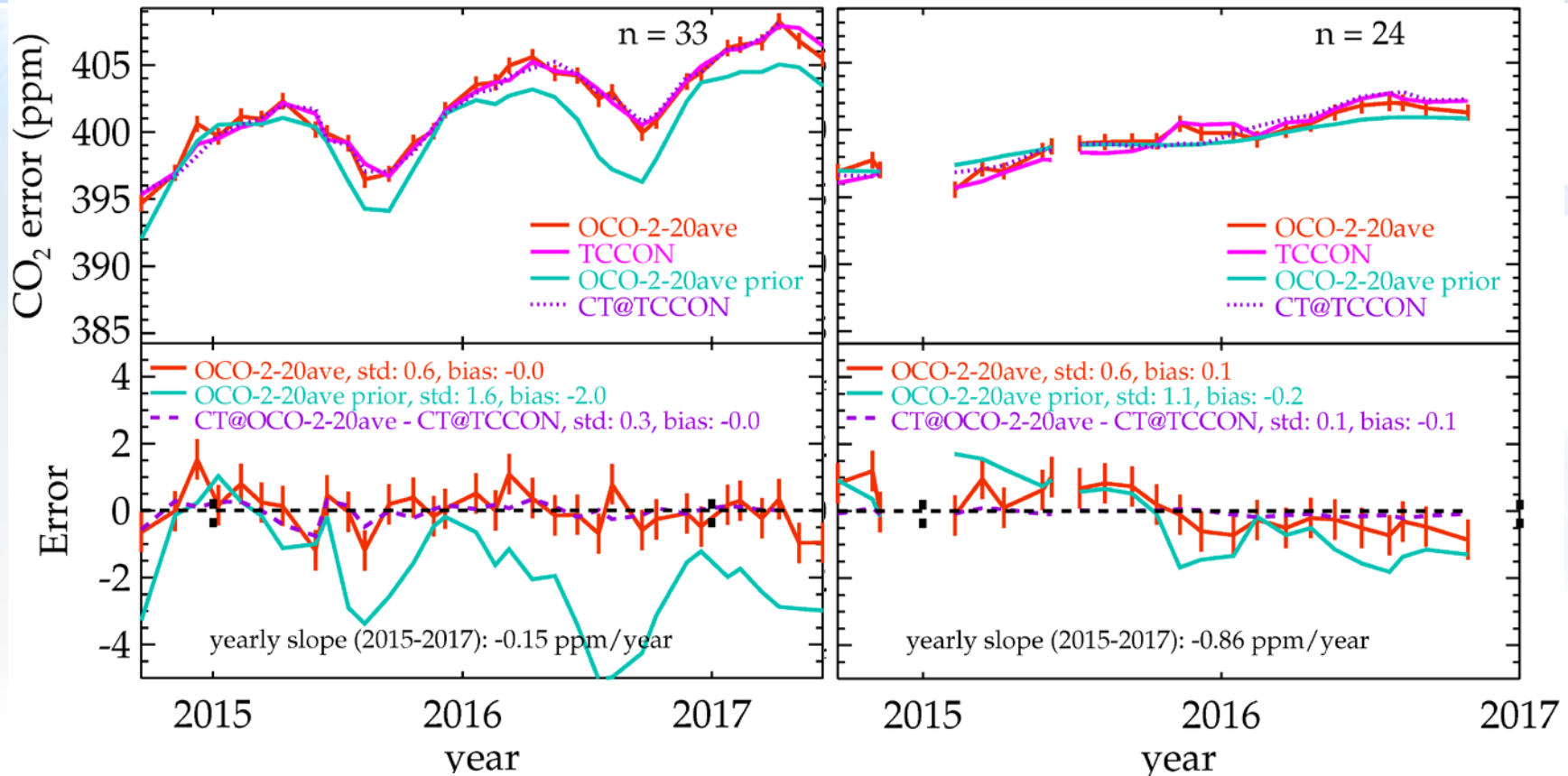±5 degrees longitude
±1 hour

Susan Kulawik 5/2018   6

Dynamic Coincidence
±5 days

$$\left(\left(\frac{\Delta Latitude}{10}\right)^2 + \left(\frac{\Delta Longitude}{30}\right)^2 + \left(\frac{\Delta Temperature}{2}\right)^2\right) < 1$$

Susan Kulawik 5/2018   7
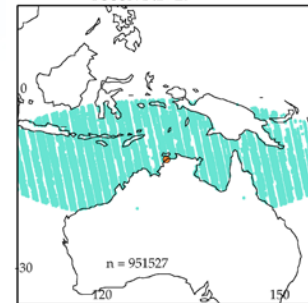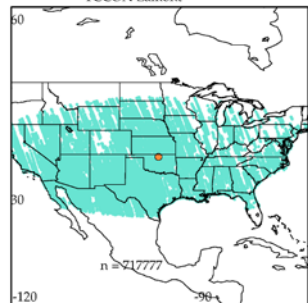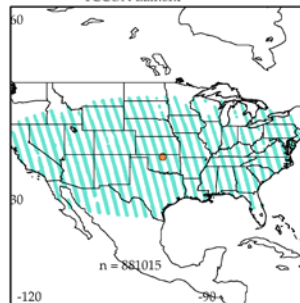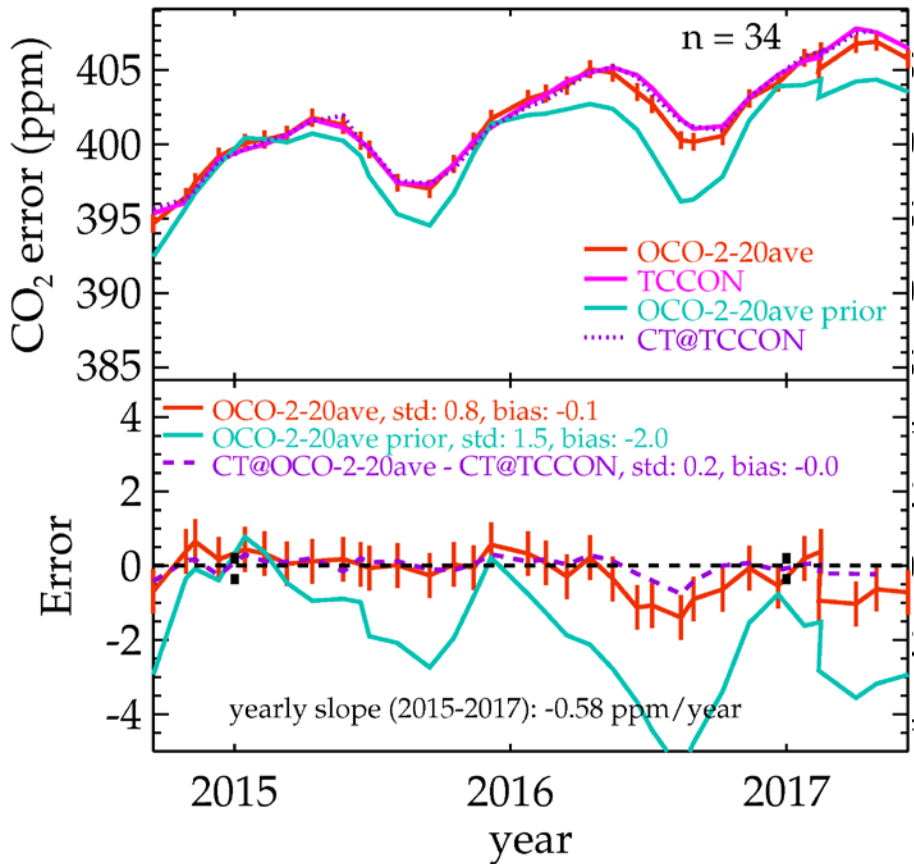
Geometric   Dynamic

ATom 1S Aug, 2016

ATom 2N Feb, 2017
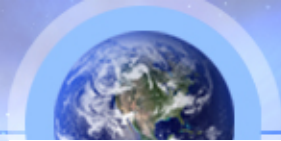
Geometric Coincidence

±3 degrees latitude
±5 degrees longitude
±9 hours

ATom profile height

9
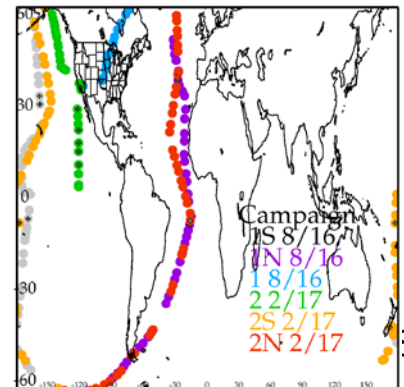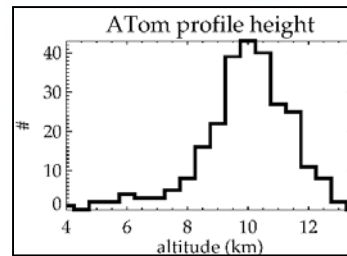
Bottom line

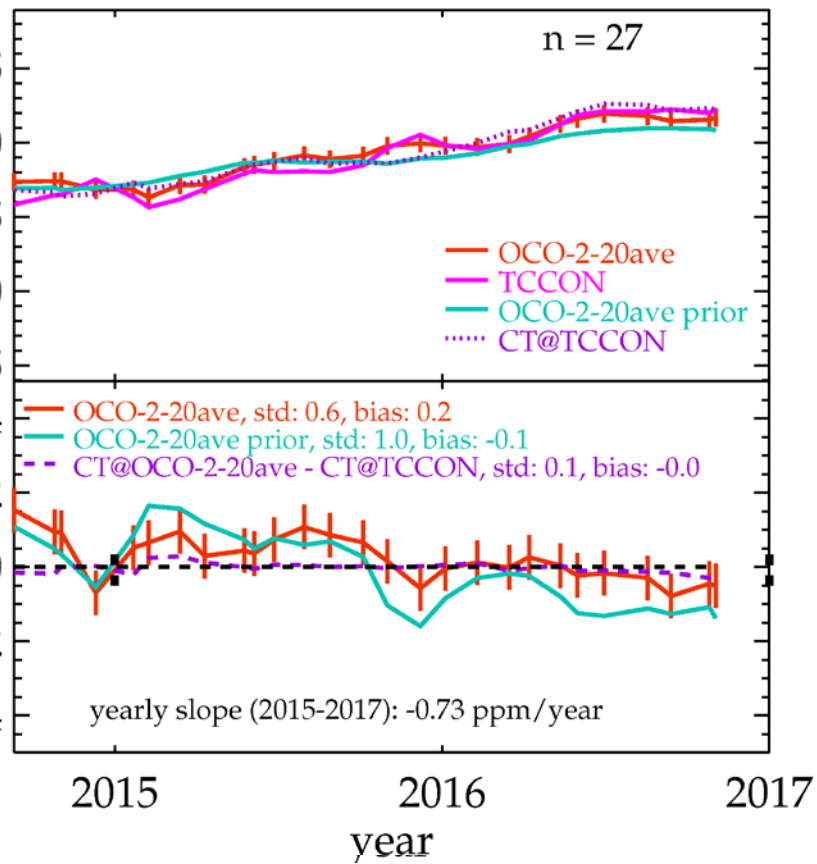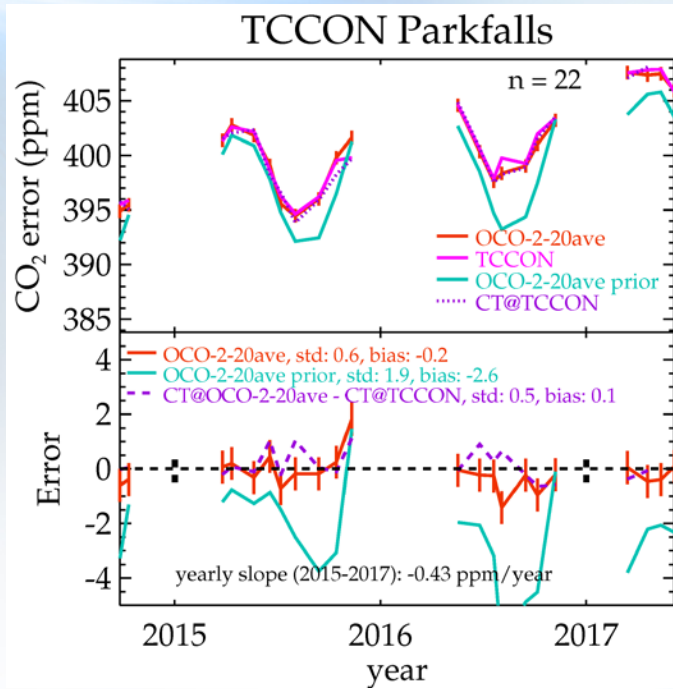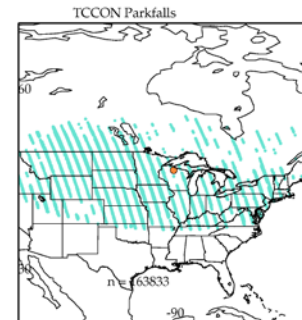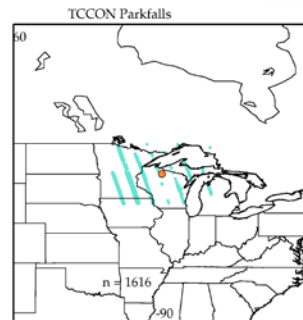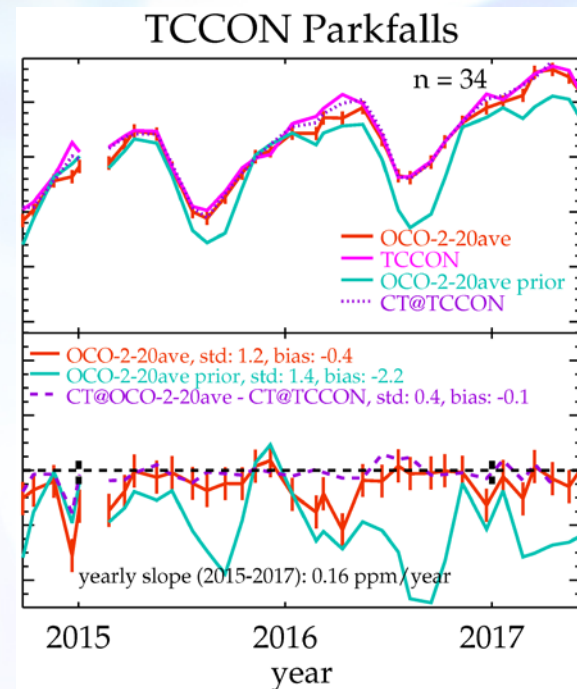|	Error, random (ppm)	Error, correlated (ppm)	Bias variability (ppm)
ACOS-GOSAT			
Land	**1.6 (0.3)**	**0.6 (0.3)**	**0.8 (0.2)**
Ocean	**1.0 (0.2)**	**0.7 (0.2)**	**0.5 (0.1)**
OCO-2 (geometric coincidence)			
Land nadir	**1.0 (0.2)**	**0.8 (0.3)**	**0.5 (0.1)**
land glint	**1.1 (0.2)**	**0.6 (0.3)**	**0.4 (0.3)**
Ocean glint	**0.6 (0.3)**	**0.6 (0.3)**	**0.5 (0.1)**
Ocean glint (ATom)	**0.8 (0.3)**	**0.2 (0.1)**	**0.4 (0.0)**
OCO-2 (dynamic coincidence)			
Land nadir	-	0.9 (0.6)	0.3 (0.2)
land glint	-	0.9 (0.7)	0.5 (0.3)
Ocean glint	-	0.9 (0.6)	0.7 (0.2)
CT2016/CT2017NRT (closest)			
Land nadir matches	0.3	0.6	0.5
Land glint matches	0.3	0.6	0.5
Ocean matches	0.1	0.7	0.5
Ocean matches (ATom)	0.4	0.3	0.5

TCCON Lamont

Legend:
- OCO-2
- Eq 1 fit: $\sqrt{0.6^2 + 0.8^2/n}$
- CT@TCCON fit: $\sqrt{0.4^2 + 0.2^2/n}$
- OCO-2 prior
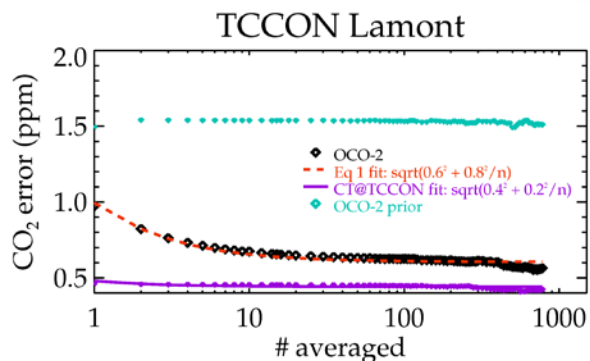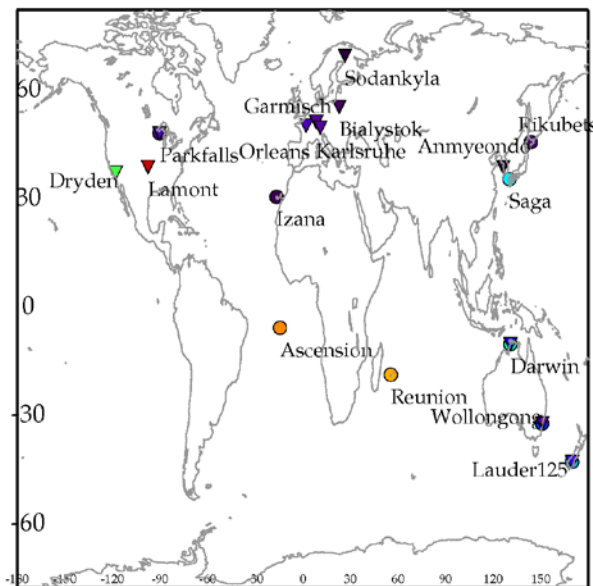
$$error = \sqrt{correlated^2 + random^2/n}$$

- 10-sec average
- land glint @ Lamont
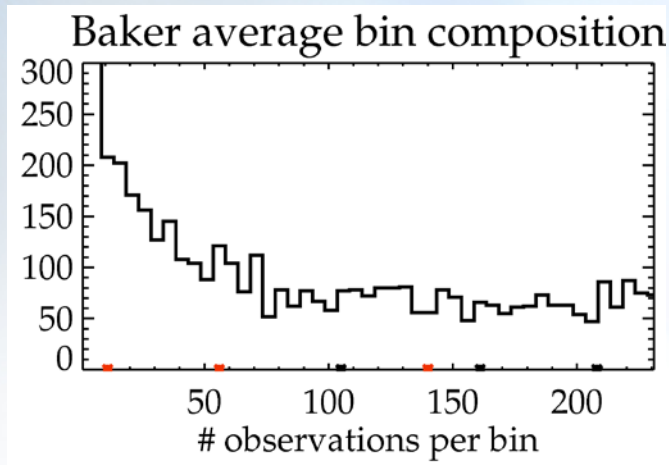
Bins with 1 obs (4% of bins, 0.05% of data)

Baker average bin composition

Lamont

Separated by # per bin
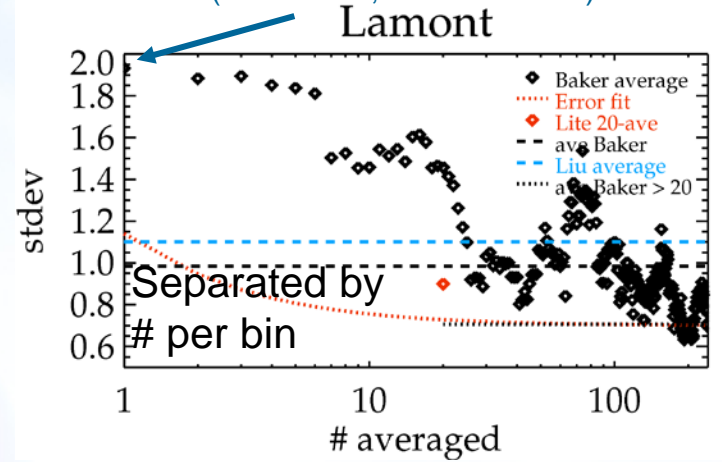
	Stdev (ppm)	Bias variability (ppm)
Land nadir		
Lite 20-obs	0.9	0.6
Baker	1.3	0.5
Baker (# > 20)	0.9	0.5
Liu	1.4	0.6

Observations in low-throughput areas have much higher errors.

Bins with 1 entry: 2 ppm
Bins with 10 entries: 1.4 ppm
Bins with 30 entries: 1.0 ppm

Need thresholds for averaged products
Or increased errors

TCCON Darwin

n = 27

OCO-2-20ave
TCCON
OCO-2-20ave prior
CT@TCCON

OCO-2-20ave, std: 0.6, bias: 0.2
OCO-2-20ave prior, std: 1.0, bias: -0.1
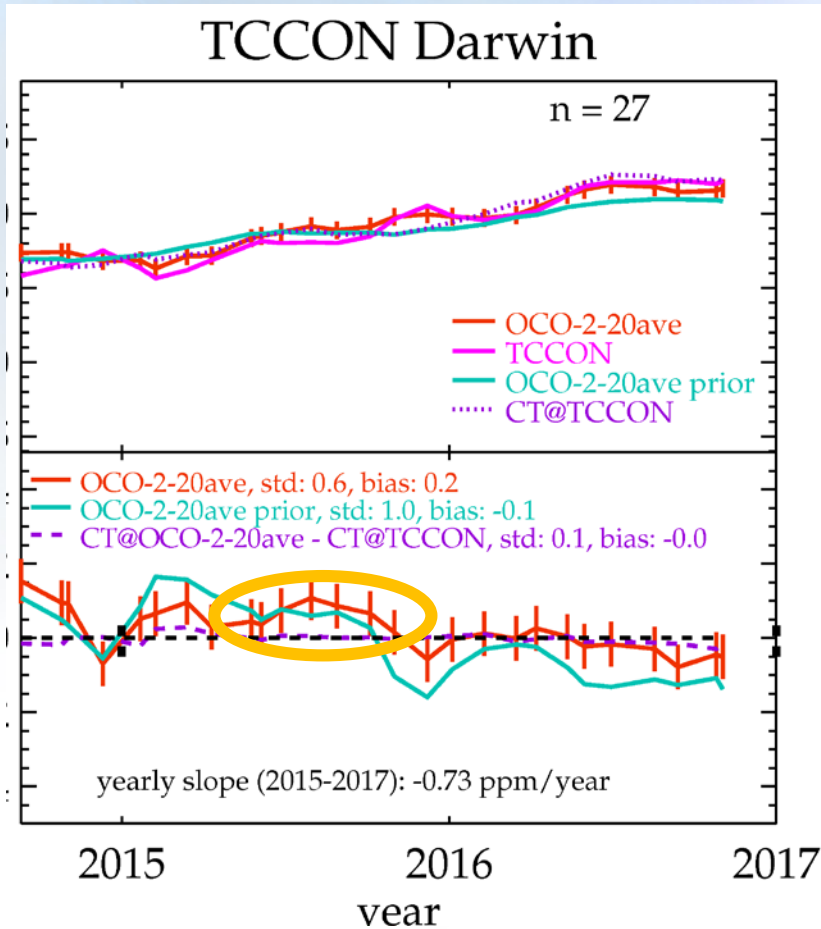CT@OCO-2-20ave - CT@TCCON, std: 0.1, bias: -0.0

yearly slope (2015-2017): -0.73 ppm/year

2015   2016   2017
year

Questions:

- **If a point is biased, how likely is its "neighbor" biased??**
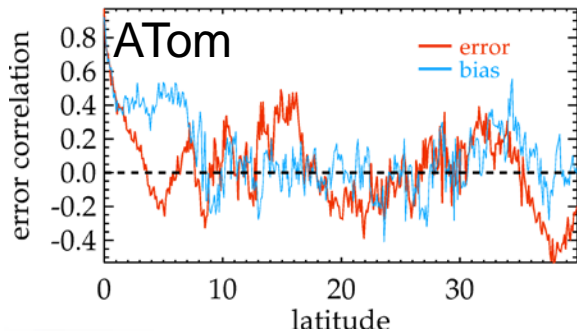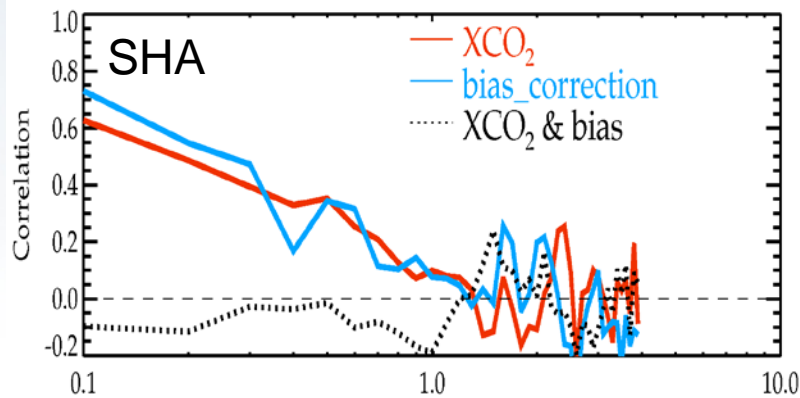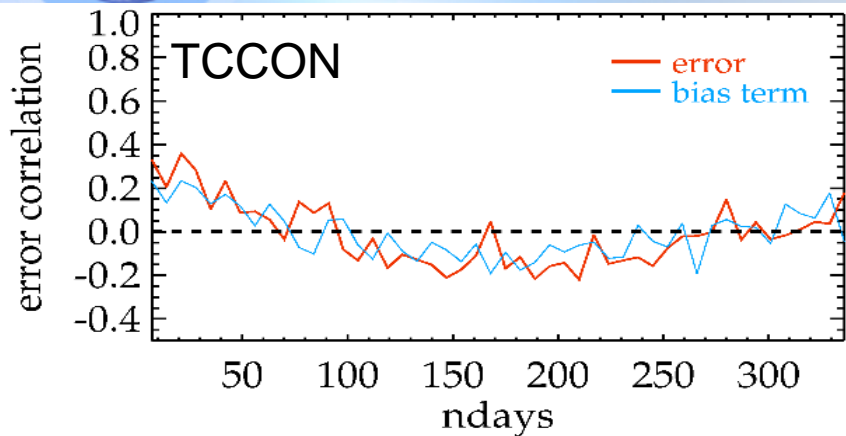- **What is the bias correlation time and distance?**

How?

- **Time correlation: Error vs. TCCON**
- **Distance correlation:**
    - **SH approximation**
    - **Error vs ATom**

Bias correlation scales

- 100 days
- 0.8 degrees
- 10 degrees

More importantly:

- *Even though XCO_2 and the bias correction term are not correlated, they have the same correlation scales!*

- **Proposal: use assimilation of bias term to characterize flux errors and inform the distances and times that can be resolved**

- All these parameters have similar correlation lengths:
  - albedo_o2a
  - albedo_sco2
  - aod_total
  - aod_water
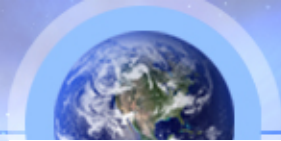 - dP
  - co2_grad_del
  - s32

Thanks for your attention

- **OCO-2 v8 looks good**
- **Biases and effects on flux estimates can be characterized through the bias correction term**
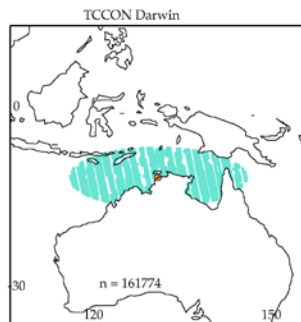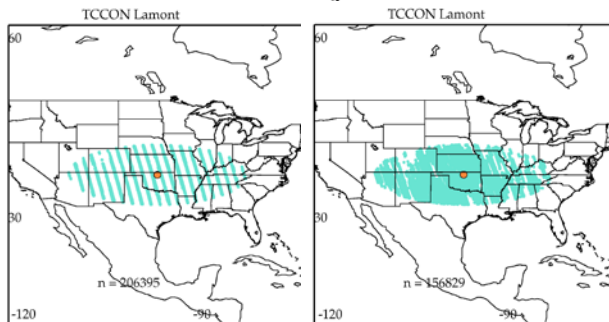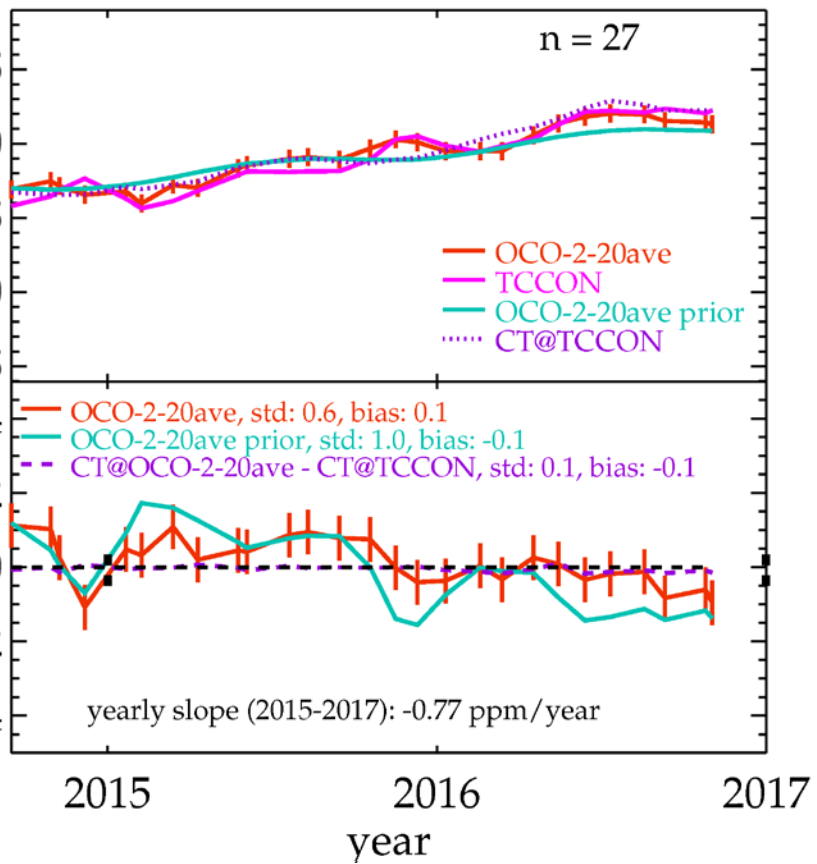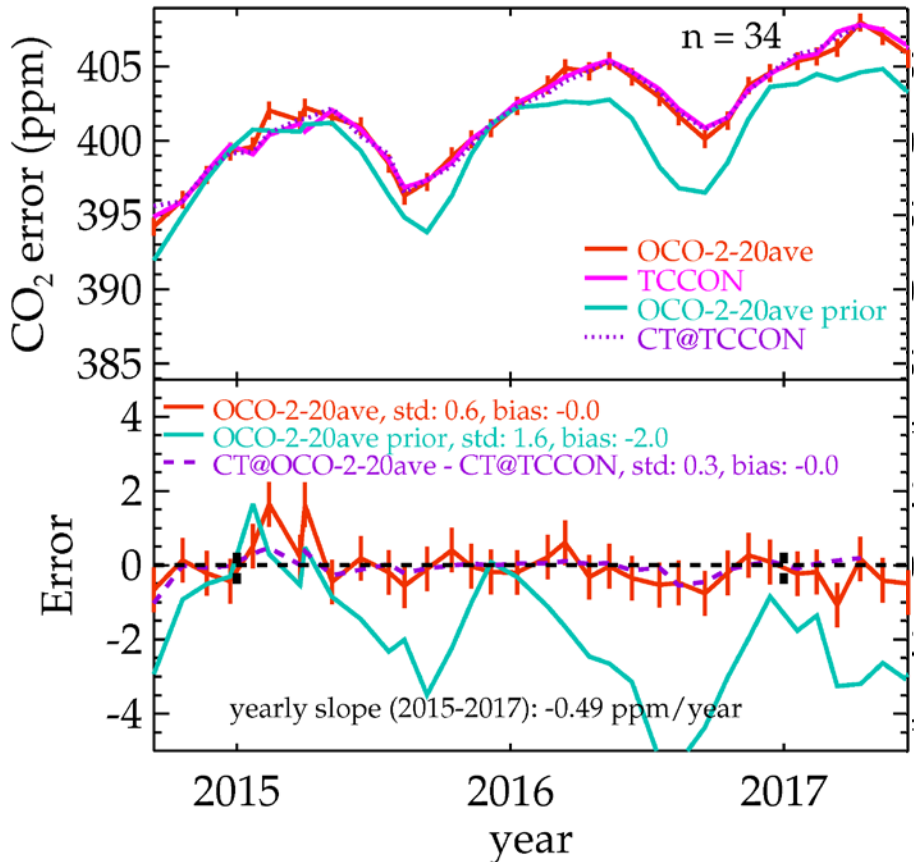
OCO-2 v8

TCCON Lamont — n = 34

TCCON Darwin — n = 27

Legend:
- OCO-2-20ave
- TCCON
- OCO-2-20ave prior
- CT@TCCON

Lamont error panel:
- OCO-2-20ave, std: 0.6, bias: -0.0
- OCO-2-20ave prior, std: 1.6, bias: -2.0
- CT@OCO-2-20ave - CT@TCCON, std: 0.3, bias: -0.0
- yearly slope (2015-2017): -0.49 ppm/year

Darwin error panel:
- OCO-2-20ave, std: 0.6, bias: 0.1
- OCO-2-20ave prior, std: 1.0, bias: -0.1
- CT@OCO-2-20ave - CT@TCCON, std: 0.1, bias: -0.1
- yearly slope (2015-2017): -0.77 ppm/year

CO_2 error (ppm) vs year

Dynamic Coincidence
±2 days
±15 degrees latitude
±5 degrees longitude
±1K

Susan Kulawik 5/2018   15