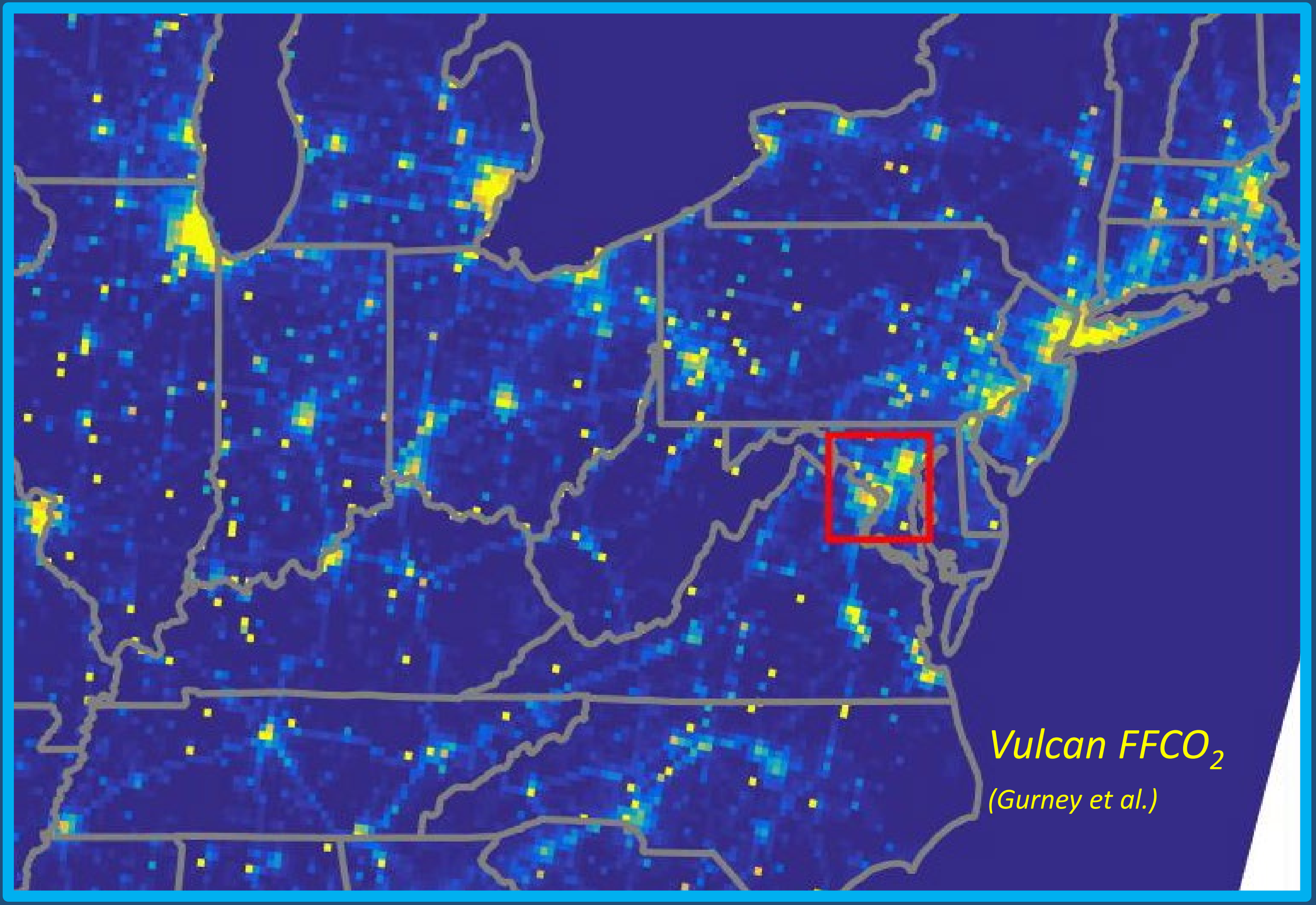
Background determination for an urban domain

Anna Karion

Israel Lopez Coto, Sharon Gourdji, Subhomoy Ghosh, Kimberly Mueller, James Whetstone (NIST)

Russ Dickerson, Xinrong Ren (University of Maryland)

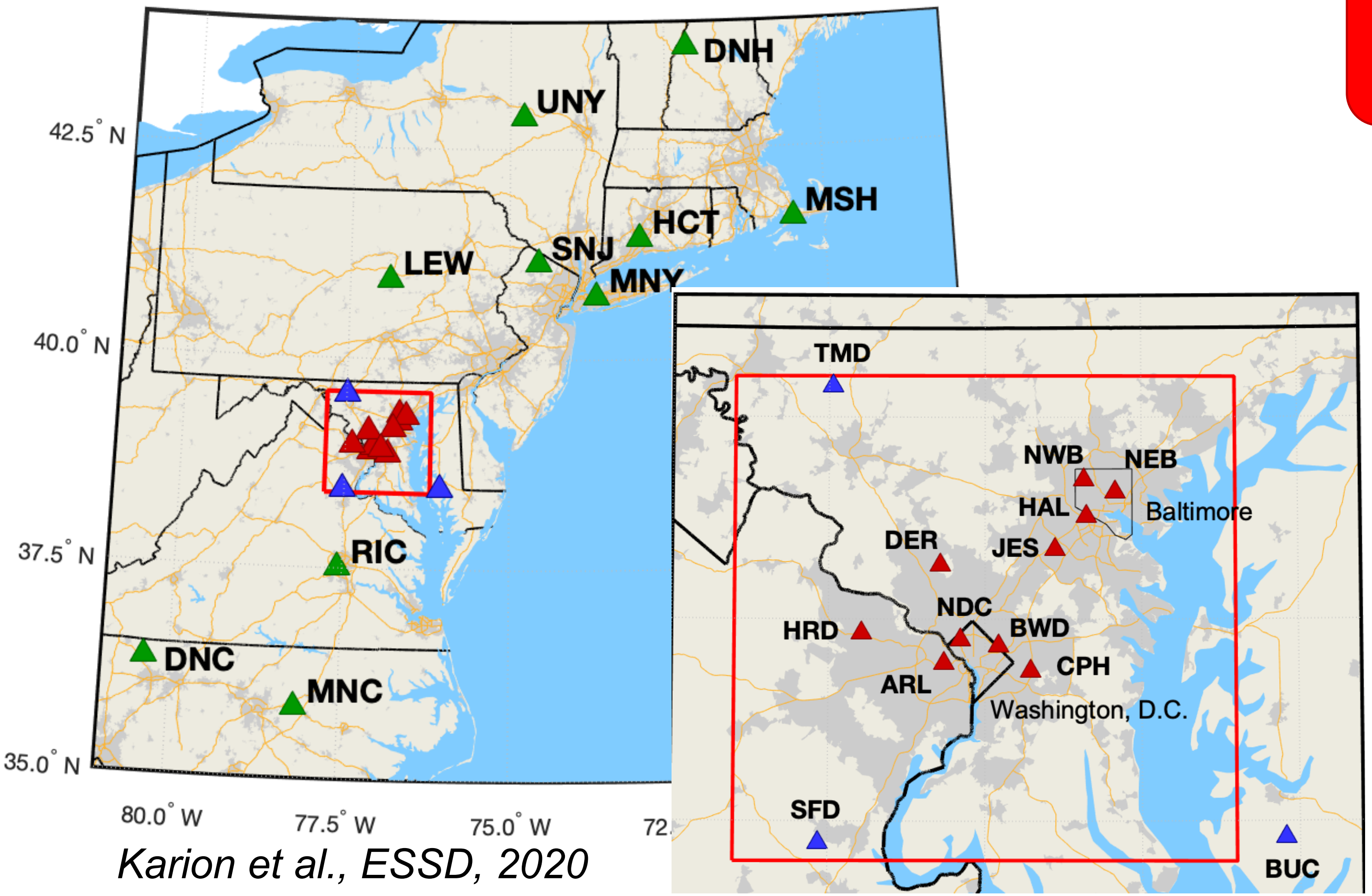
Steve Prinzivalli, Mike Stock, Elizabeth DiGiangi, Clayton Fain (Earth Networks)



Northeast Corridor Partners

NIST	University of Maryland	Earth Networks	…and more
David Allen Subhomoy Ghosh Sharon Gourdji Israel Lopez Coto Kimberly Mueller Kuldeep Prasad Tamae Wong James Whetstone	Russ Dickerson Ross Salawitch Ning Zeng Xinrong Ren Hao He Doyeon Ahn	Steve Prinzivalli Clayton Fain Bryan Biggs Michael Stock Charlie Draper William Callahan **Scripps & NASA/JPL**: Peter Salameh, Kris Verhulst, Jooil Kim, & LA Megacities team	**Northern Arizona University**: Kevin Gurney **Boston University**: Lucy Hutyra & team **Bowdoin College**: Barry Logan **CUNY**: Andrew Reinmann **DOE/ORNL**: Melanie Mayes & Jeff Warren **Purdue University & Stony Brook University**: Paul Shepson, Joe Pitt **NOAA/ESRL**: Colm Sweeney, John Miller, Isaac Vimont **U. Michigan**: Eric Kort & team **U. Colorado/GNS Science**: Jocelyn Turnbull **Penn State**: Ken Davis & team

The Northeast Corridor: Washington/Baltimore

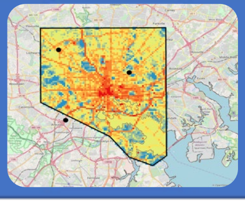


Karion et al., ESSD, 2020

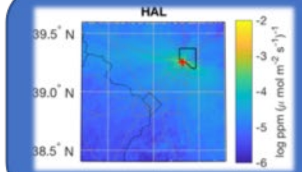
Aircraft campaigns
- U. Maryland
- Stonybrook/Purdue

Tower network
- Earth Networks
- NIST

Flask analysis
- NOAA / CU
- GNS Science



Emissions modeling
- NAU (Hestia)



Atmospheric modeling
- NIST

Biosphere
- SIF Testbed (BU +)
- VPRM (NIST)

Definition of Background

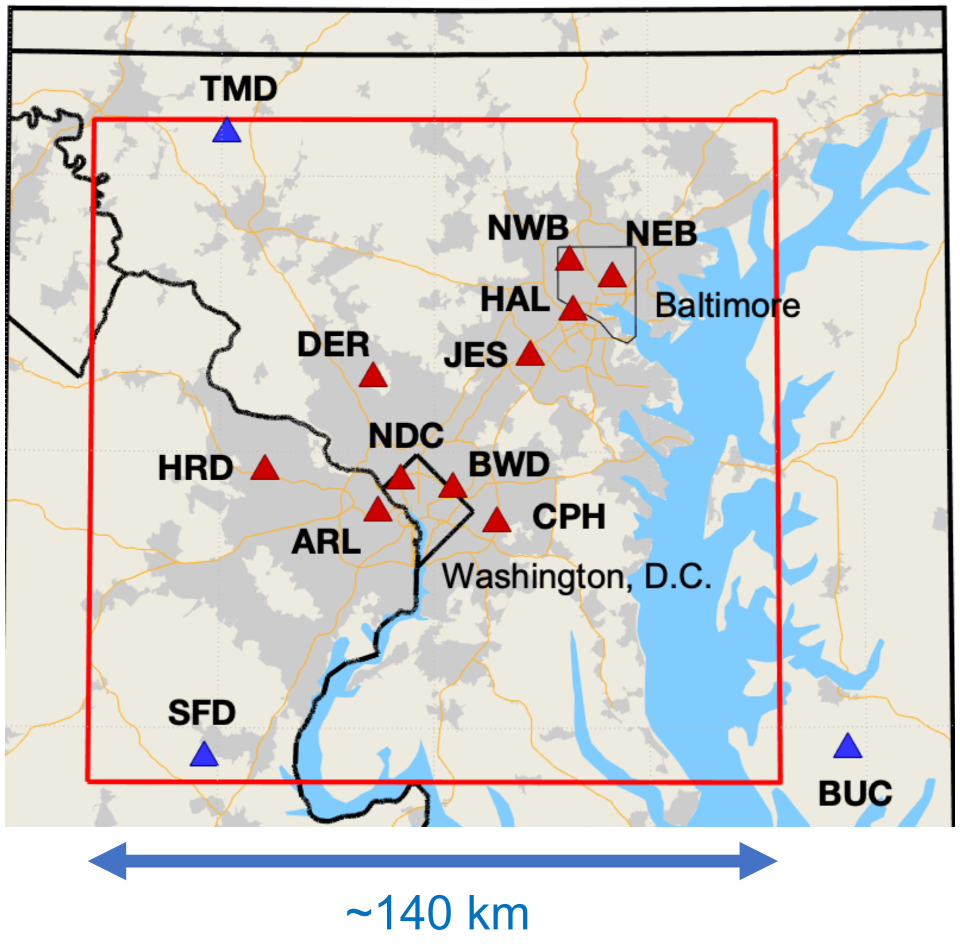
$$y = y_{BG} + y_{enh}$$

mole fraction observed at a tower

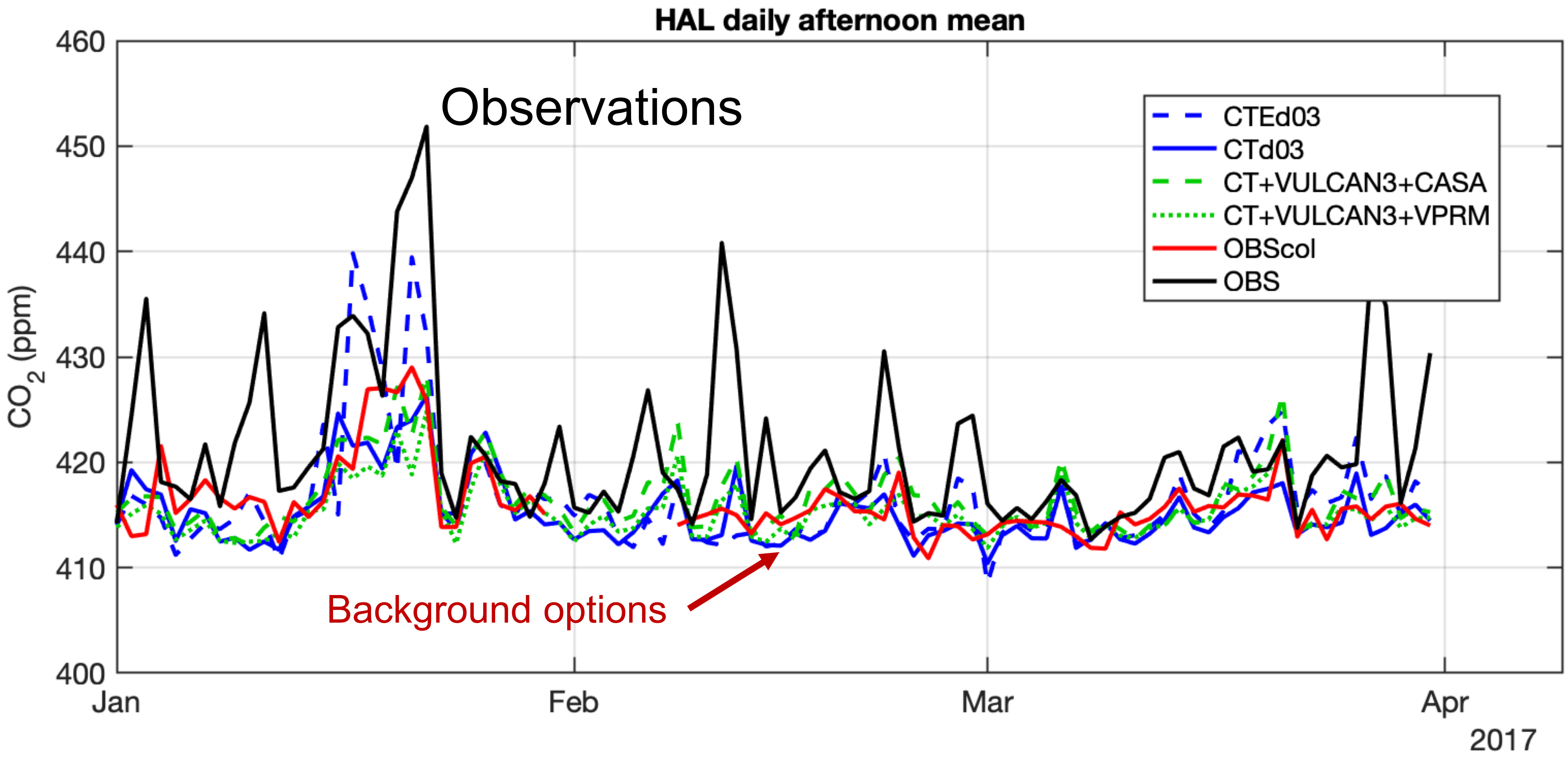
background mole fraction for the tower

enhancement at the tower due to fluxes inside the domain of interest (red box)

The background is the mole fraction a tower would measure if fluxes inside the domain were zero.



Motivation

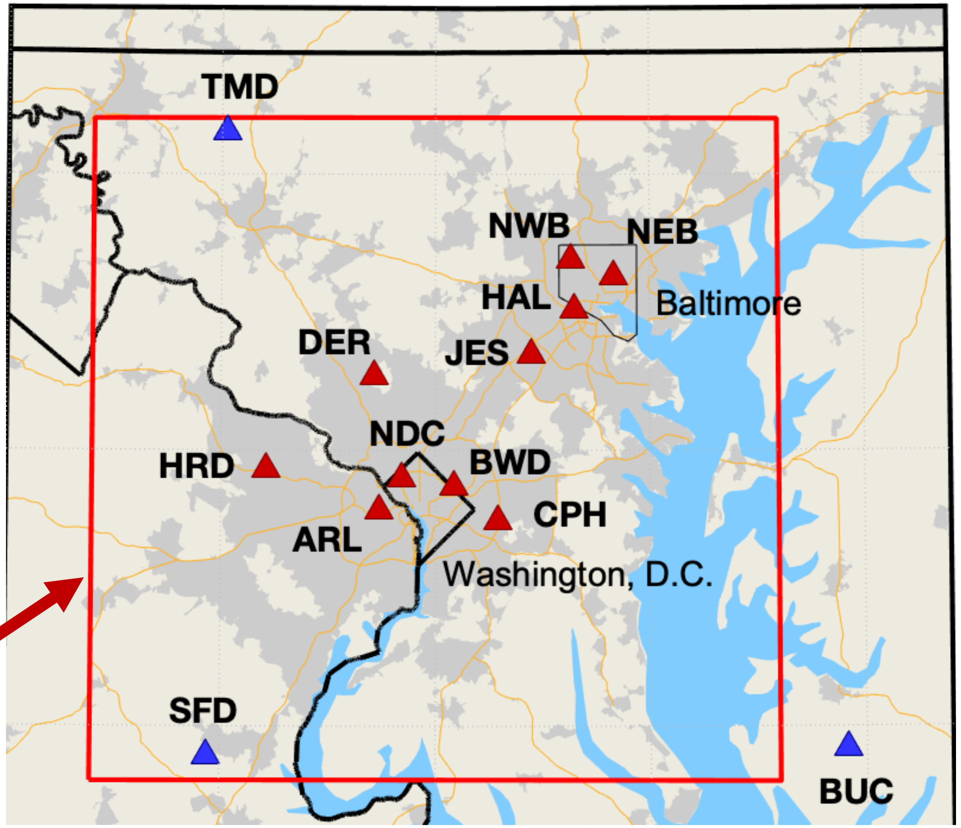


HAL daily afternoon mean
460
450
440
430
420
410
400
CO_2 (ppm)
Jan
Feb
Mar
Apr
2017
Observations
Background options
CTEd03
CTd03
CT+VULCAN3+CASA
CT+VULCAN3+VPRM
OBScol
OBS

Washington/Baltimore analysis

- Use 1-yr inversion period: Nov 2016 – Oct 2017
- Hourly WRF-STILT footprints with particle back trajectories (500 particles per footprint)
- 6 urban sites (NEB, NWB, JES, HAL, ARL, NDC)
- 3 background sites (BUC, TMD, SFD)

Refer to this as “inner” or urban domain

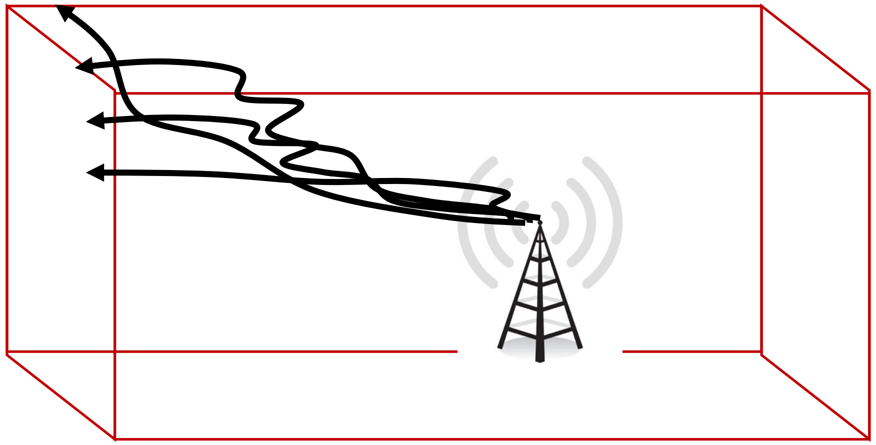


Background methods (3 basic methods)

1. Sample global model at boundary edges using particle trajectories
2. Two-component method (Mueller et al 2018).
3. Upwind observation-based

Method 1: Sampling Global Model

Sample Global model 4D CO_2 or CH_4 fields at the point when each particle exits the inner domain; average their concentrations.



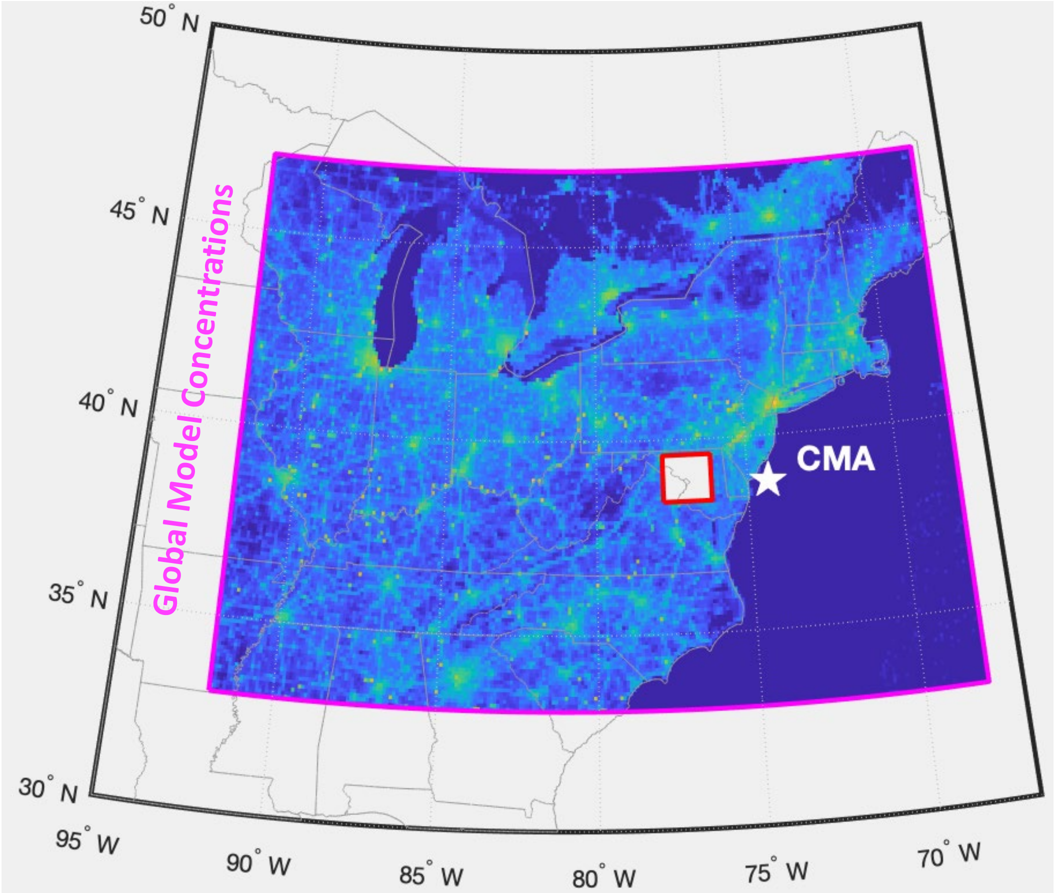
CO_2: CT-v2019, CT-Europe (1x1, 3 hourly)

Method 2: Two-component background

$$y_{obs} = y_{BG} + y_{enh}$$

$$y_{obs} = \underbrace{y_{BGfar} + y_{BGnear}}_{y_{BG}} + y_{enh}$$

y_{BGfar} calculated same as Method 1: Sample a Global model at the edge of the outer domain.

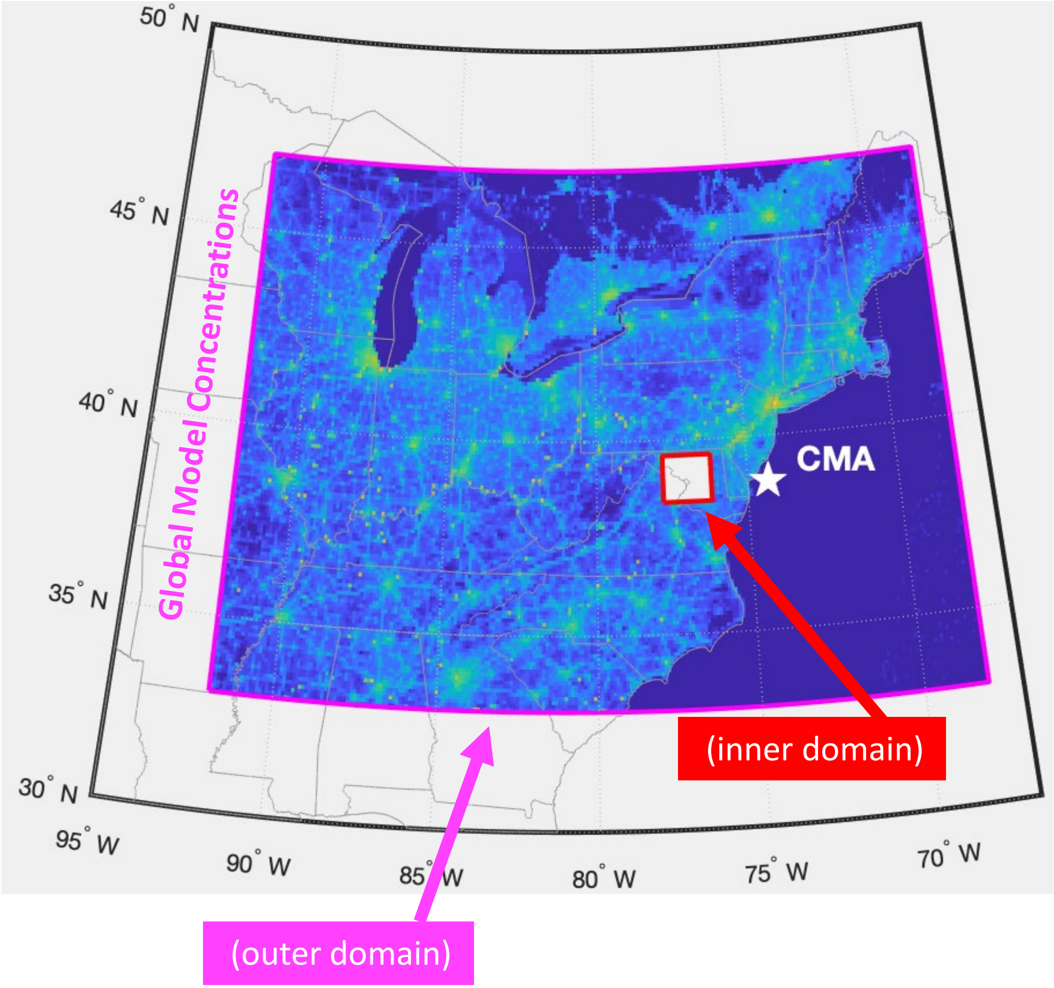


CMA is a NOAA aircraft site we use later in the analysis – shown here for reference

Method 2: Two-component background

$$y_{obs} = \underbrace{y_{BGfar} + y_{BGnear}}_{y_{BG}} + y_{enh}$$

- Use existing inventories with our WRF-STILT footprints to model y_{BGnear} in outer domain.
- Set fluxes to zero inside the inner domain
- CO_2:
  - Fossil: Vulcan 3.0 (2015)
  - Bio: VPRM, CASA



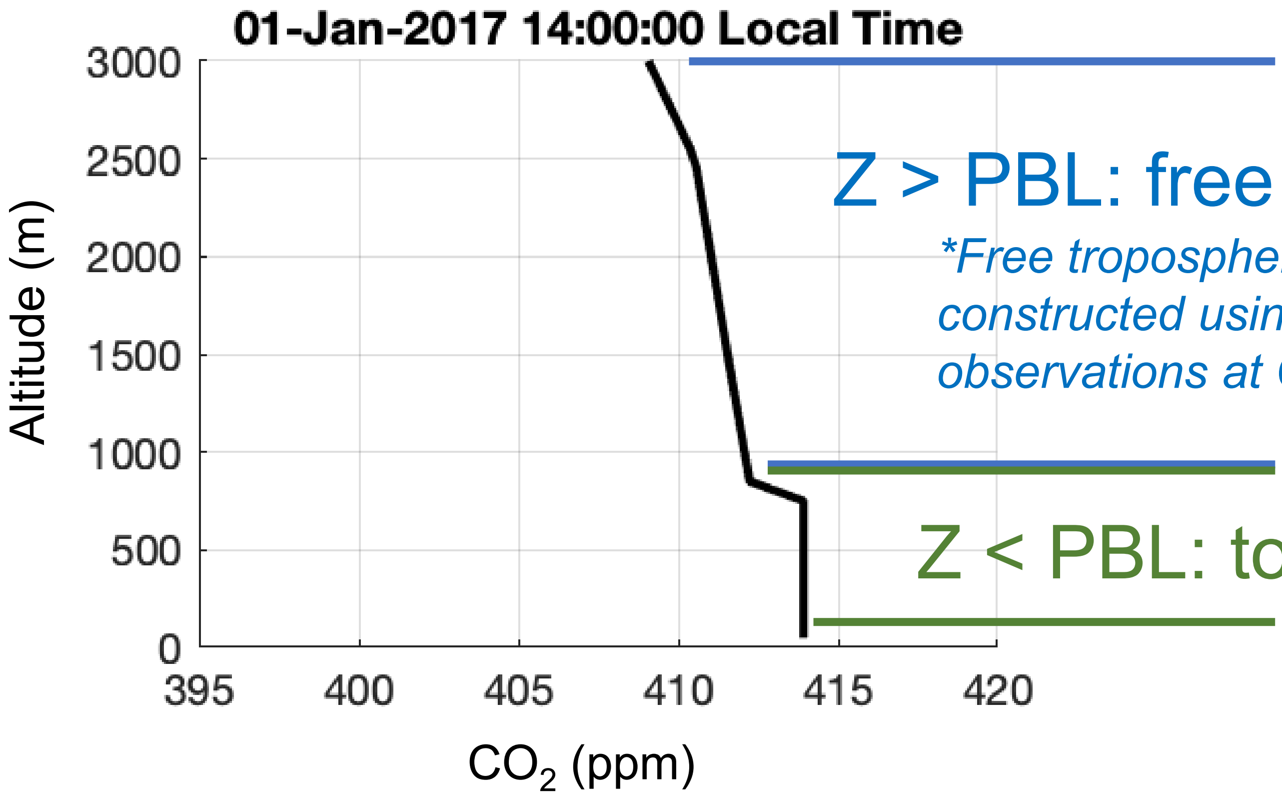
Method 3: Use upwind tower observations

A. Sample nearest background tower at the time of particle exit ("lagged observations") (not usually done)

B. Sample nearest background tower at the same time as the urban tower ("afternoon observations") (similar to Lauvaux et al.)

C. Sample a vertical column distribution above the nearest background tower at the time of particle exit (similar to Sargent et al.).
   - Investigated several ways to construct this column, used an OSSE to minimize bias.

Constructing vertical column at upwind sites: Afternoon hours

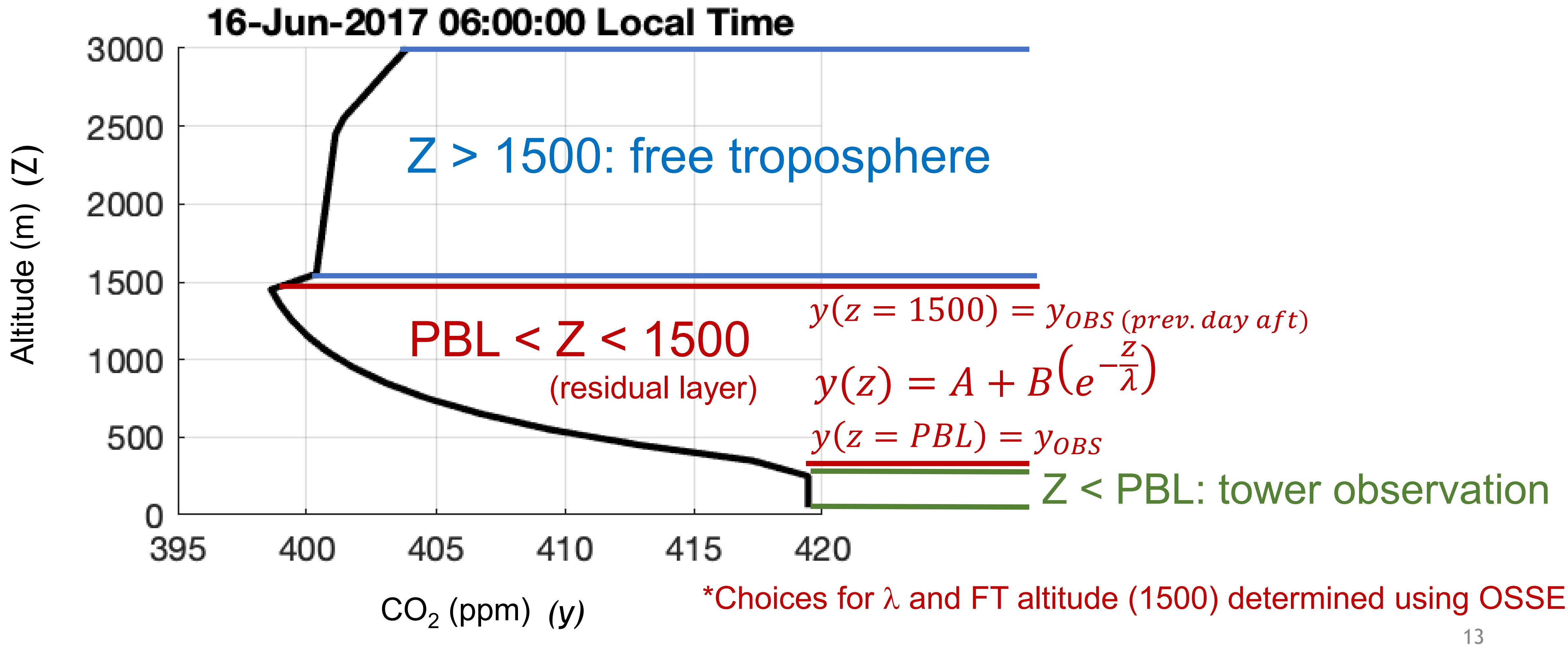


Z > PBL: free troposphere*

**Free troposphere value is derived from a "curtain" constructed using binned/smoothed NOAA aircraft observations at CMA.*

Z < PBL: tower observation

Constructing vertical column at upwind sites: non-afternoon hours



*Choices for λ and FT altitude (1500) determined using OSSE.

Synthetic study for CO_2

$$y_{obs} = \underbrace{y_{BGfar} + y_{BGnear}}_{y_{BG} = \text{“true background”}} + y_{enh}$$

- Create synthetic observations for urban **and** background sites.
- Create synthetic background columns.
- Evaluate background method by comparing with true background.
- Perfect meteorology, perfect fluxes – just look at how the upwind tower column (sampled by STILT particles) represents the true background for a given urban tower.

(method very similar as published in Mueller et al.)

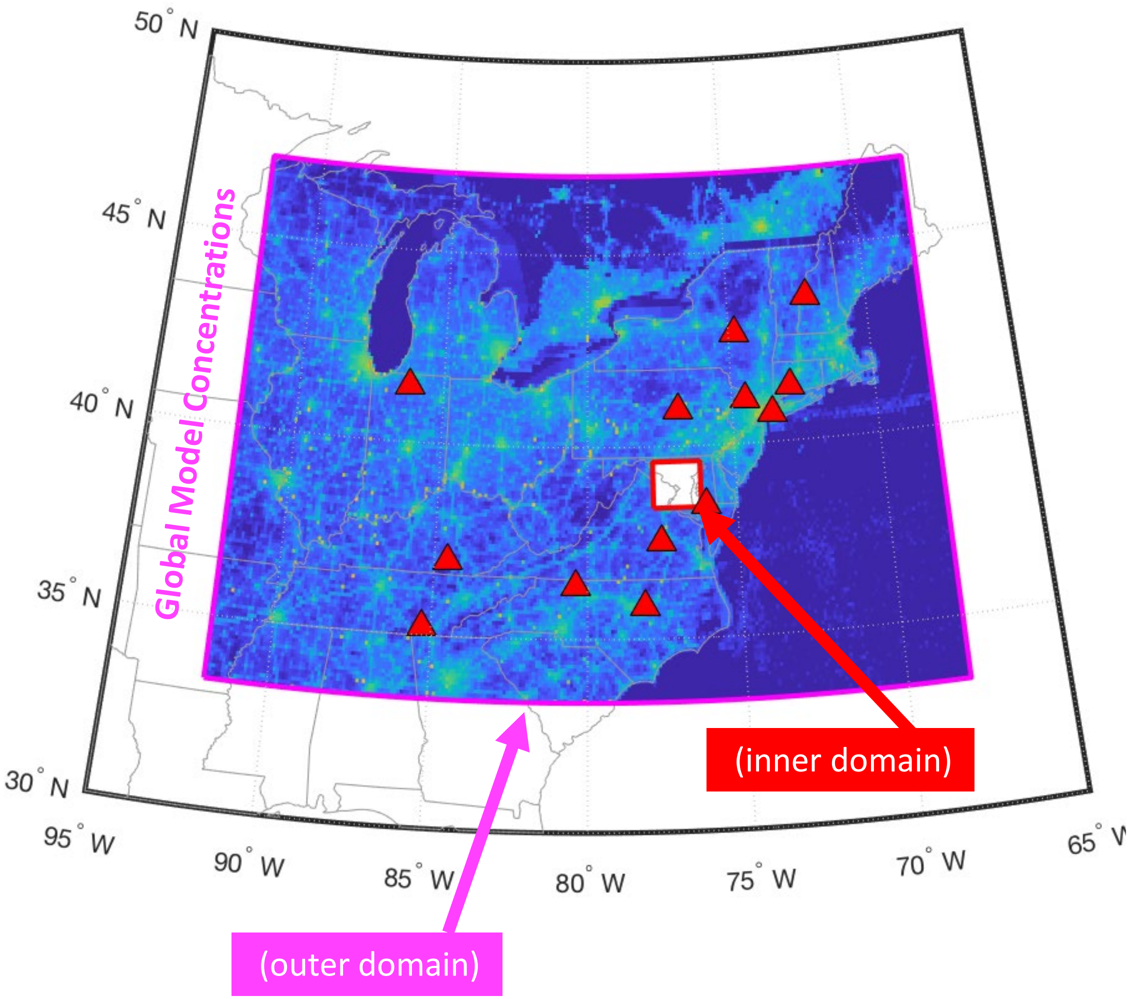
Synthetic study for CO_2

$$y_{obs} = \underbrace{y_{BGfar} + y_{BGnear}}_{y_{BG} = \text{“true background”}} + y_{enh}$$

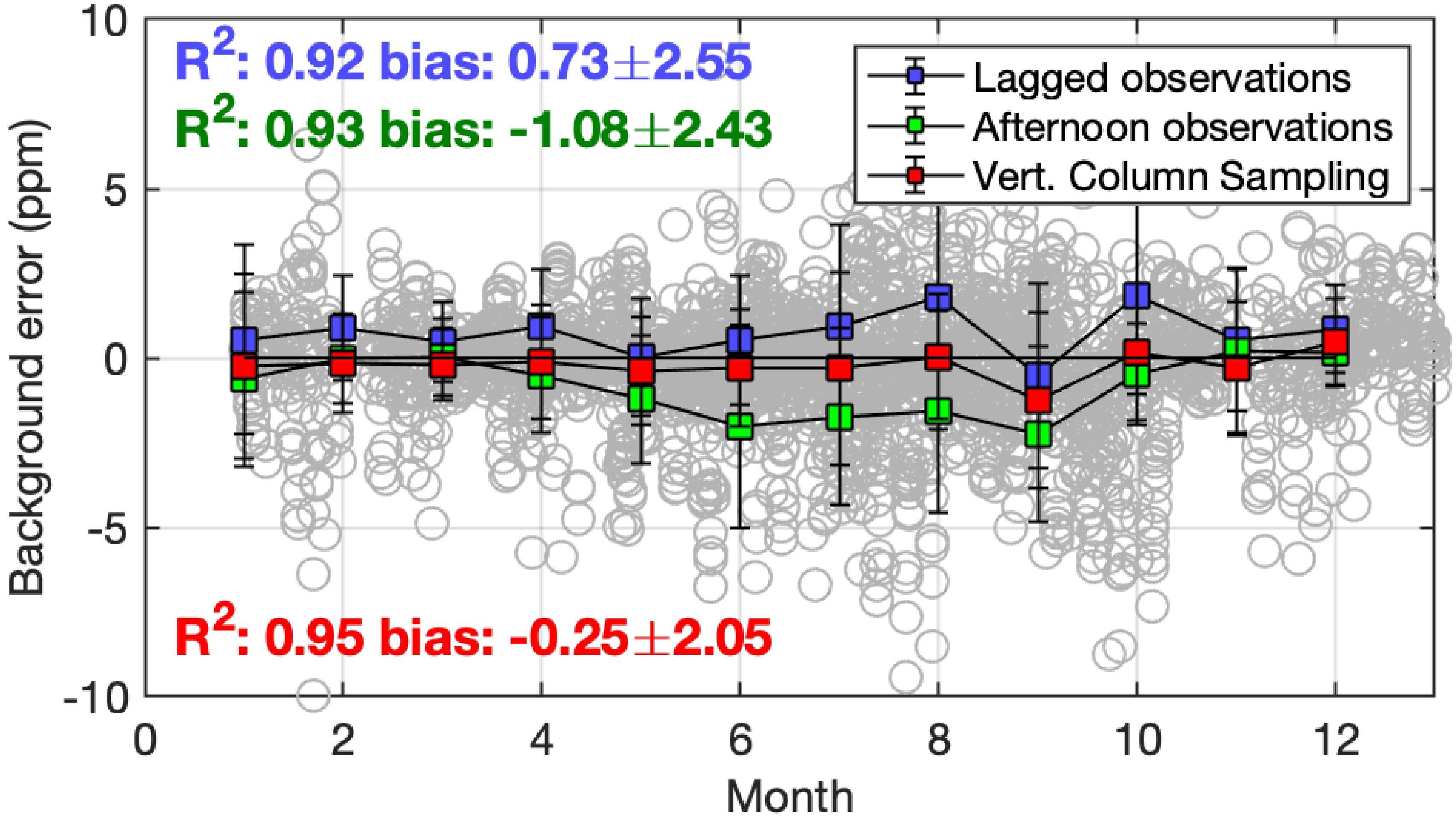
y_{BGfar} = CT-v2019

y_{BGnear} = outer domain flux convolutions using VPRM + Vulcan, zeroed out in inner domain

y_{enh} = enhancements from fluxes (VPRM+Vulcan) in inner domain.



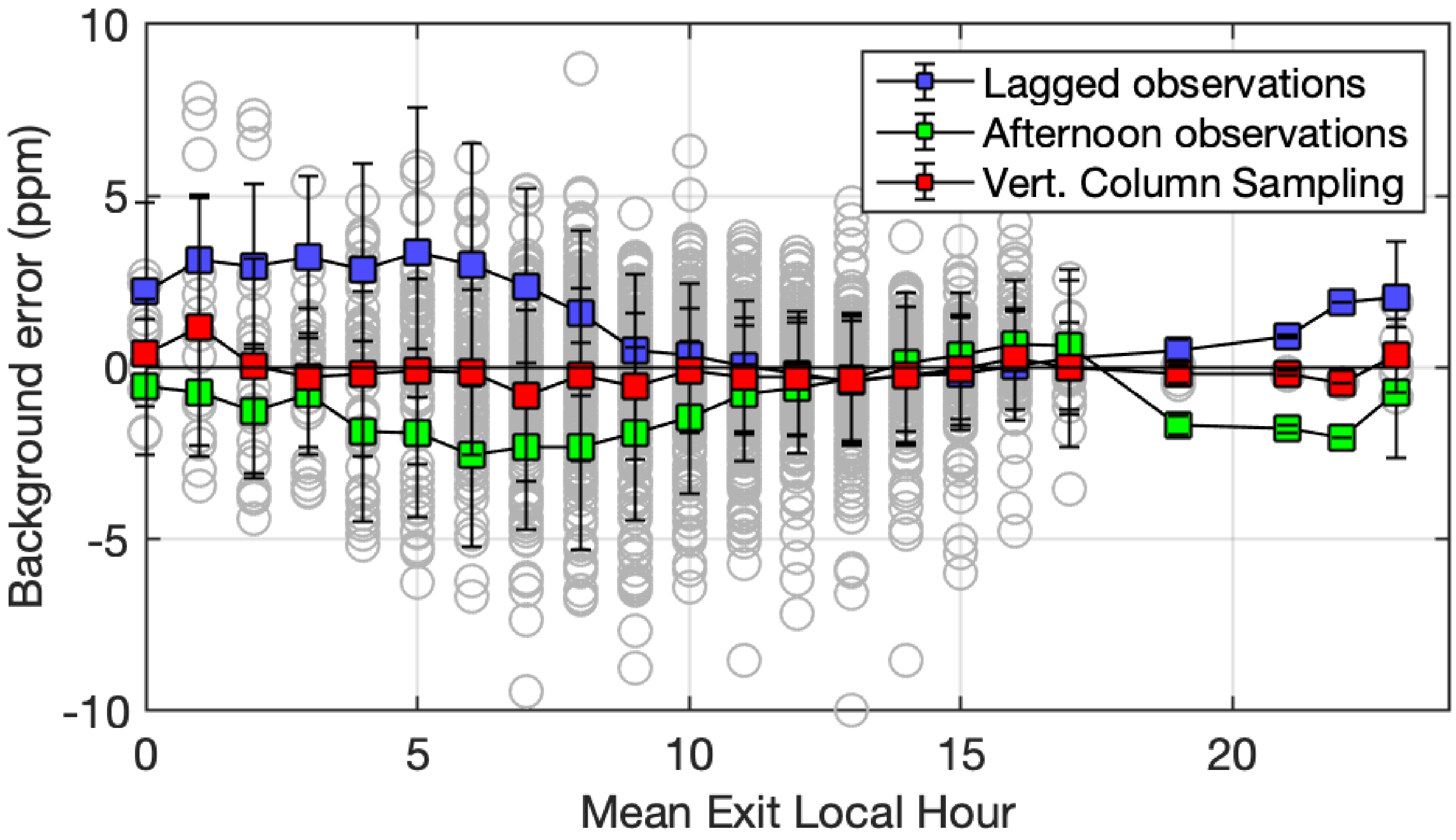
CO_2 (OSSE result) error/bias (Estimate – Truth)



- Using Afternoon observations at the upwind tower causes low bias in the summer.
- Using observations at upwind tower lagged by travel time causes high bias.
- Column background less biased and has a smaller standard deviation, but still noisy.

These conclusions are specific to our network design, location of our towers.

CO_2 (OSSE result) error/bias (Estimate – Truth)



Can we evaluate against observations?

Sure!

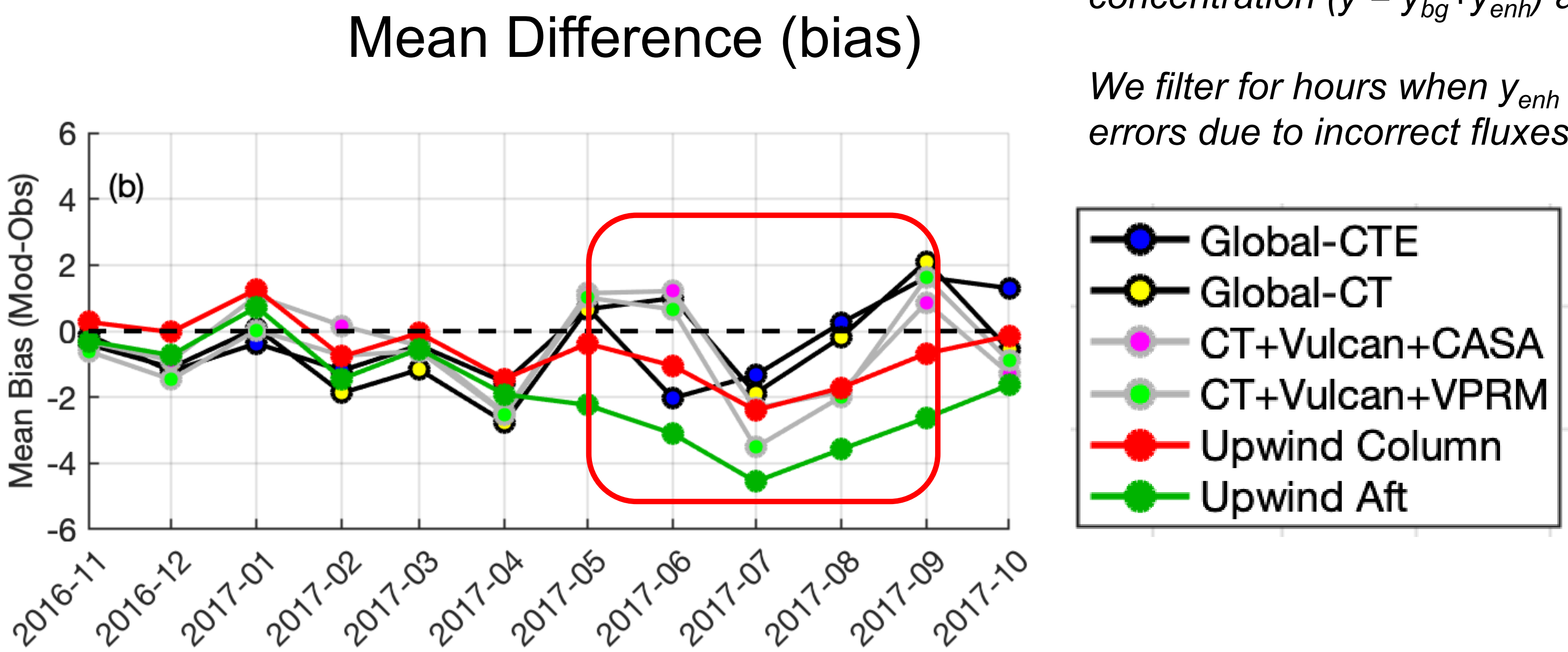
- Compare modeled to real observations at urban sites for different backgrounds.

- Limit analysis to hours where the background dominates mole fraction at urban sites: i.e. when footprints are below the 10^{th} percentile, (e.g. during high-wind events &/or high PBL)

Summary of background methods compared and evaluated

Abbreviation	Type of background	y_{BGfar}	y_{BGnear}	y_{BG}
CTd03 Global-CT	Global model sampling at inner domain boundary			CarbonTracker v2019 (Jacobson, et al., 2020)
CTEd03 Global-CTE	Global model sampling at inner domain boundary			CarbonTracker Europe (Peters et al., 2010)
CT+Vulcan+CASA	2-component background	CarbonTracker v2019	Vulcan 3.0* (Gurney) + CASA (Zhou/Williams)	$y_{BGfar} + y_{BGnear}$
CT+Vulcan+VPRM	2-component background	CarbonTracker v2019	Vulcan 3.0* + VPRM	$y_{BGfar} + y_{BGnear}$
OBScol Upwind column	Upwind observations			Sampled from a vertical column
OBSaftbg Upwind aft	Upwind observations			Mean afternoon average from same day minus y_{enh}

*FFDAS is used in portion of domain in Canada (outside Vulcan range)

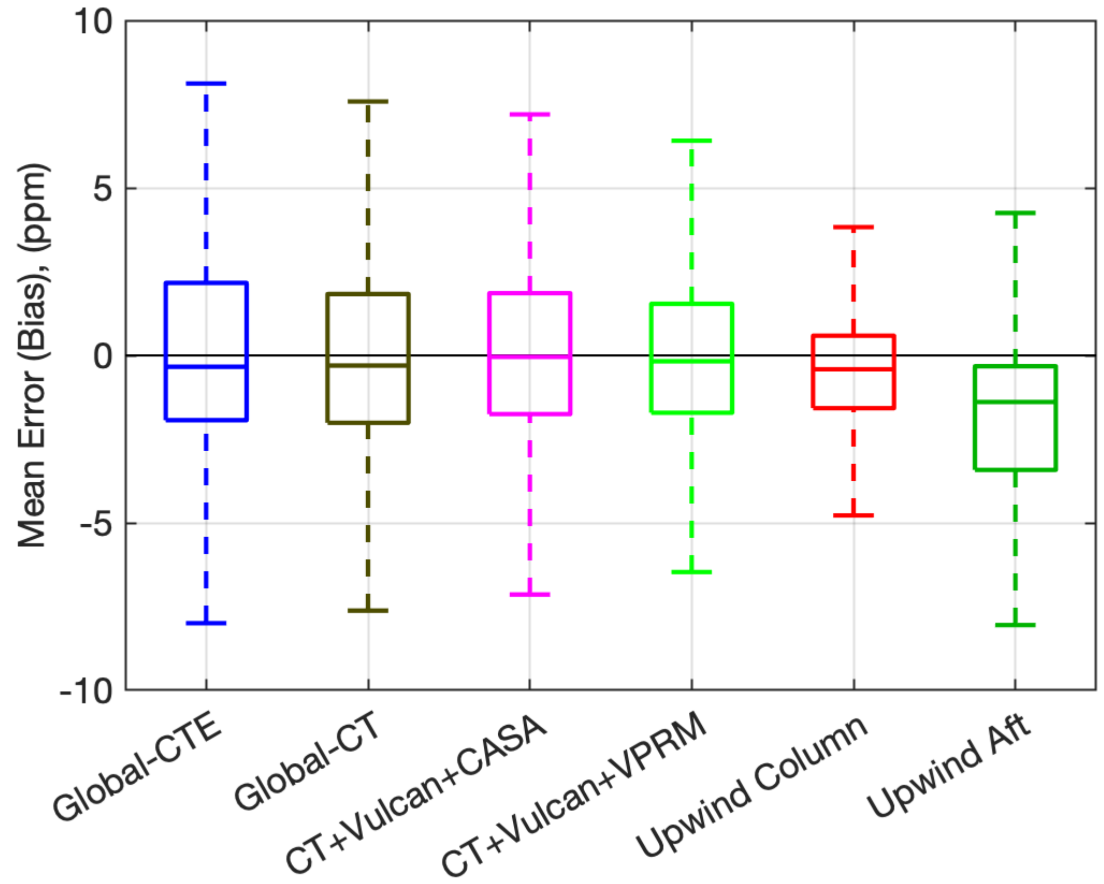


Note: this comparison is now of the full modeled concentration ($y = y_{bg}+y_{enh}$) against observations.

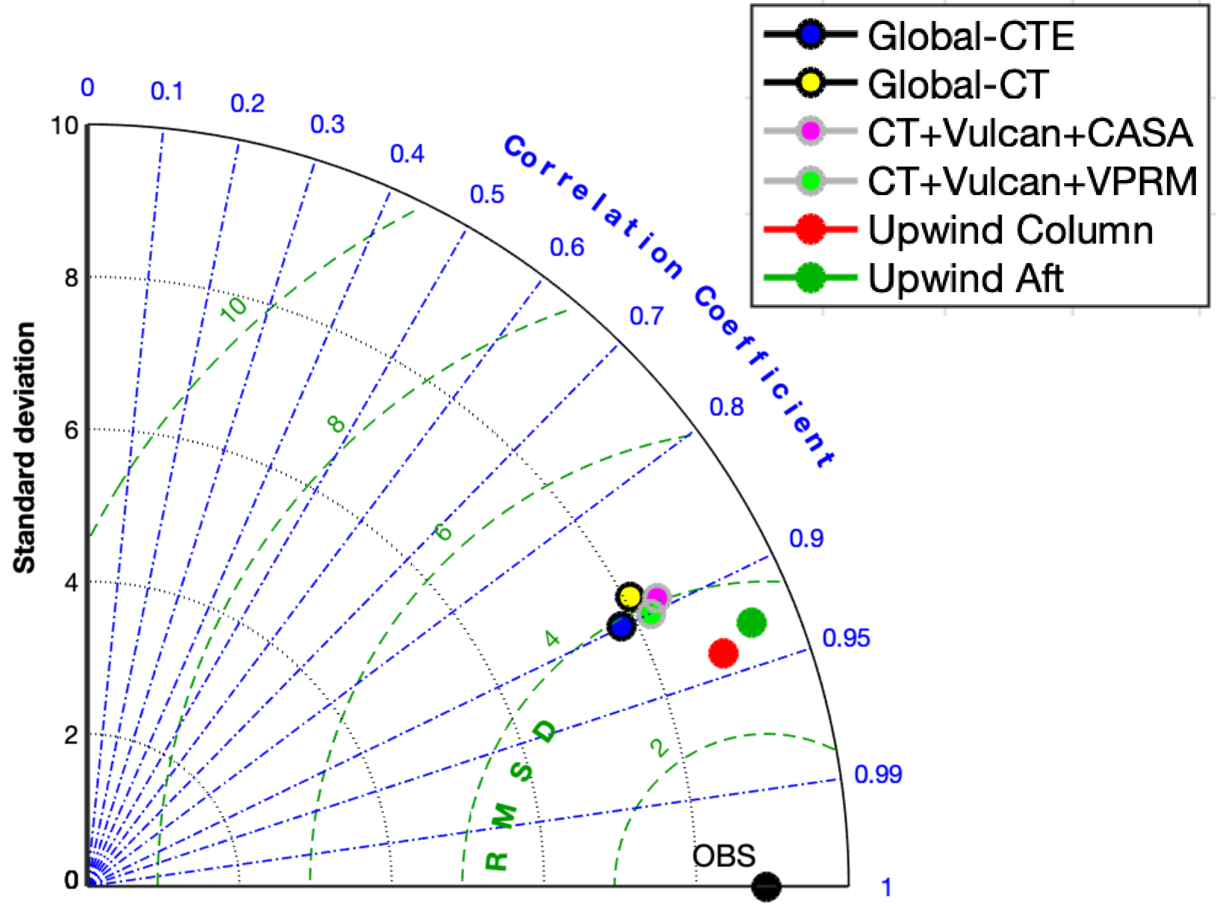
We filter for hours when y_{enh} is small to minimize errors due to incorrect fluxes inside the domain.

Column-based upwind background performs well in general, but shows low bias in summer. Some of this could be due to fluxes inside domain being incorrect in summer – even though we limit to time periods where they are small.

Two ways to look at the results: Bias (left) and Variability (right)

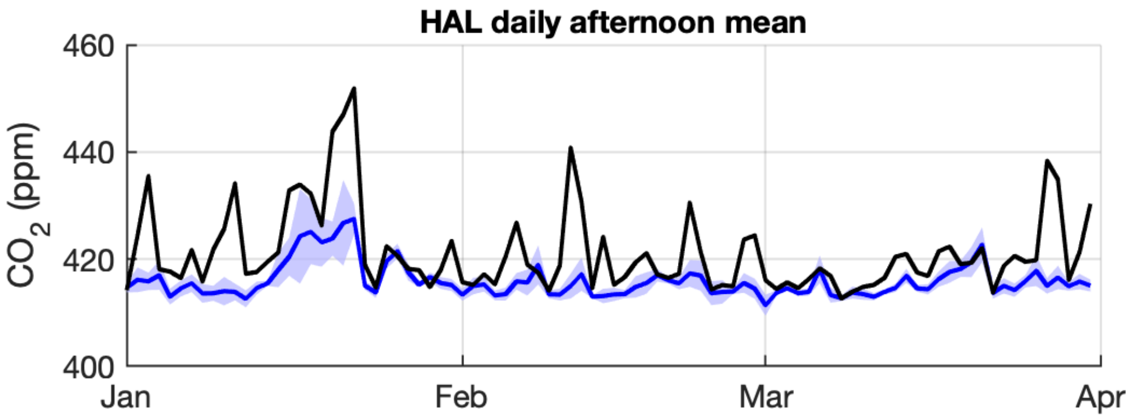


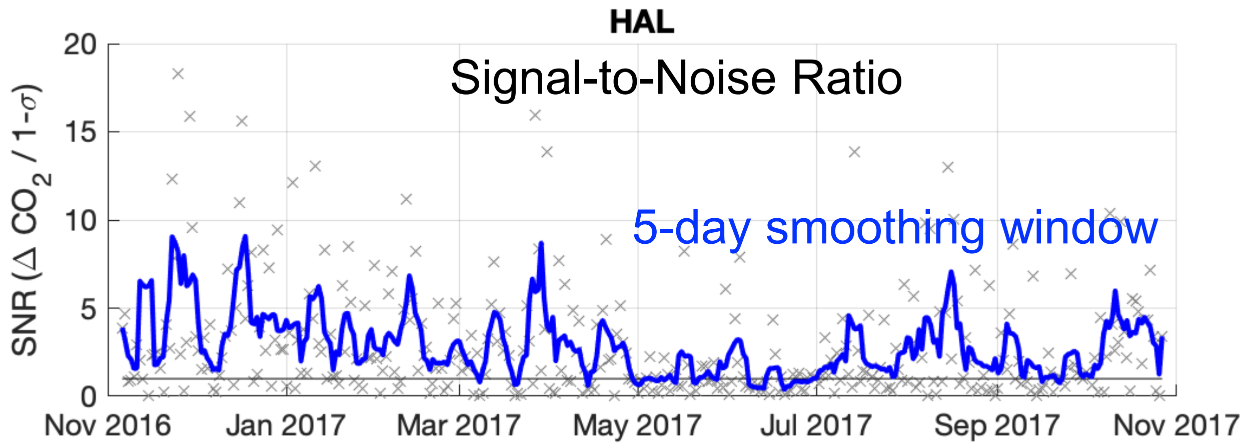
Hourly model-obs, all sites together, aft only, whole year

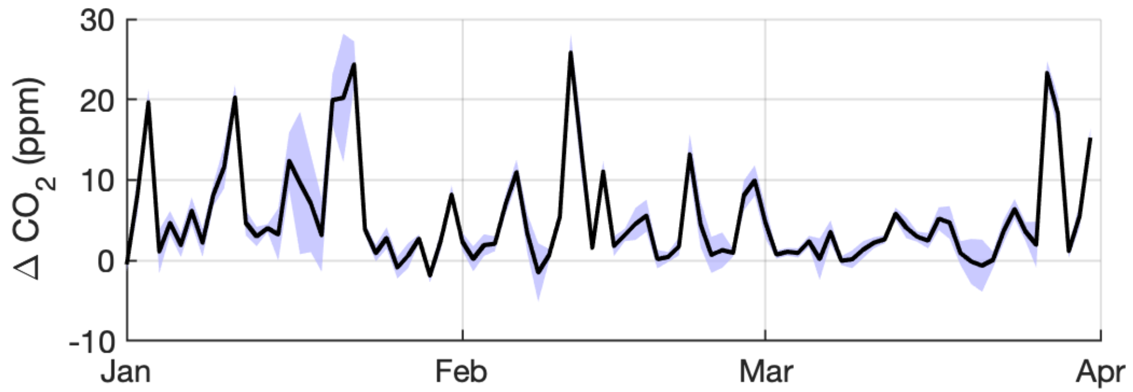


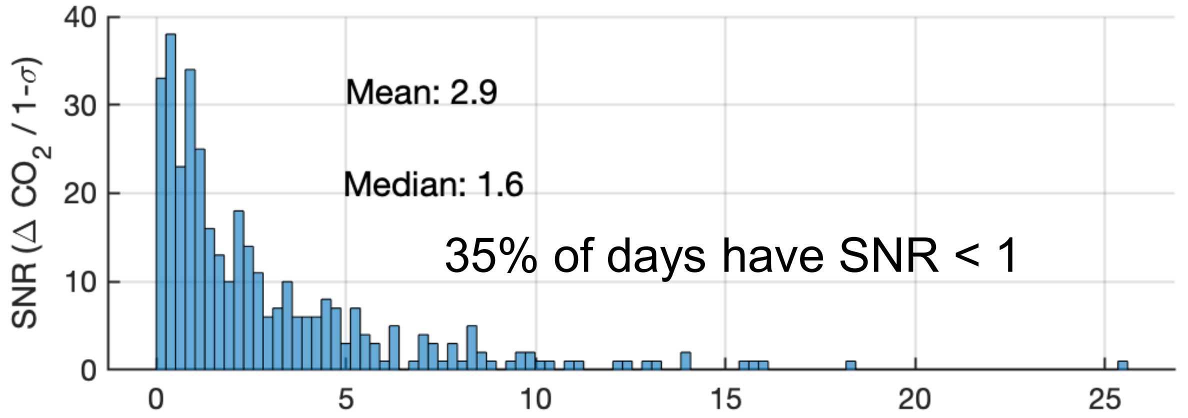
Taylor diagram indicates that the model using the column-based background is closest to the observations and has the highest correlation over the year.

Uncertainty: use spread of backgrounds?





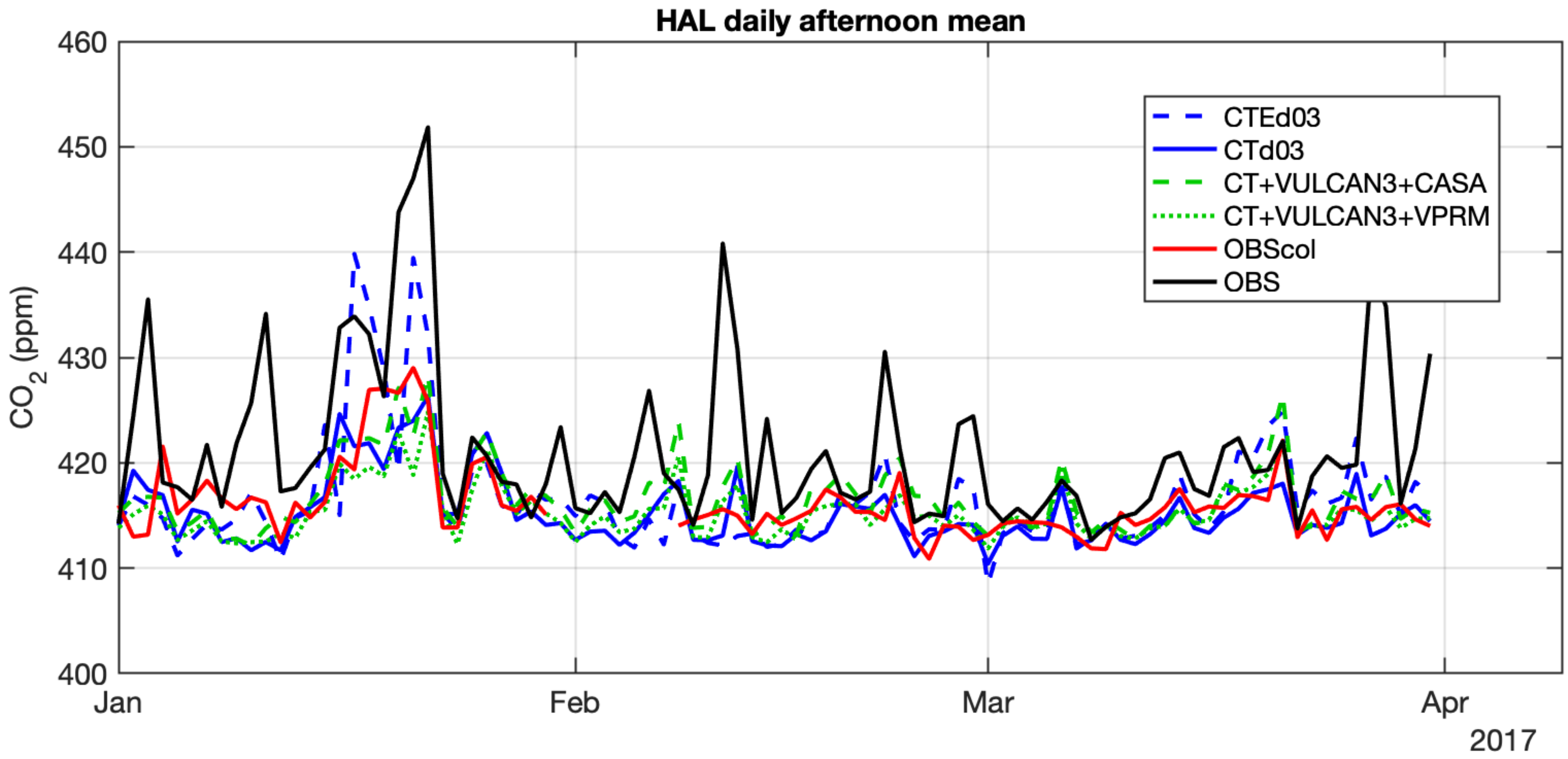




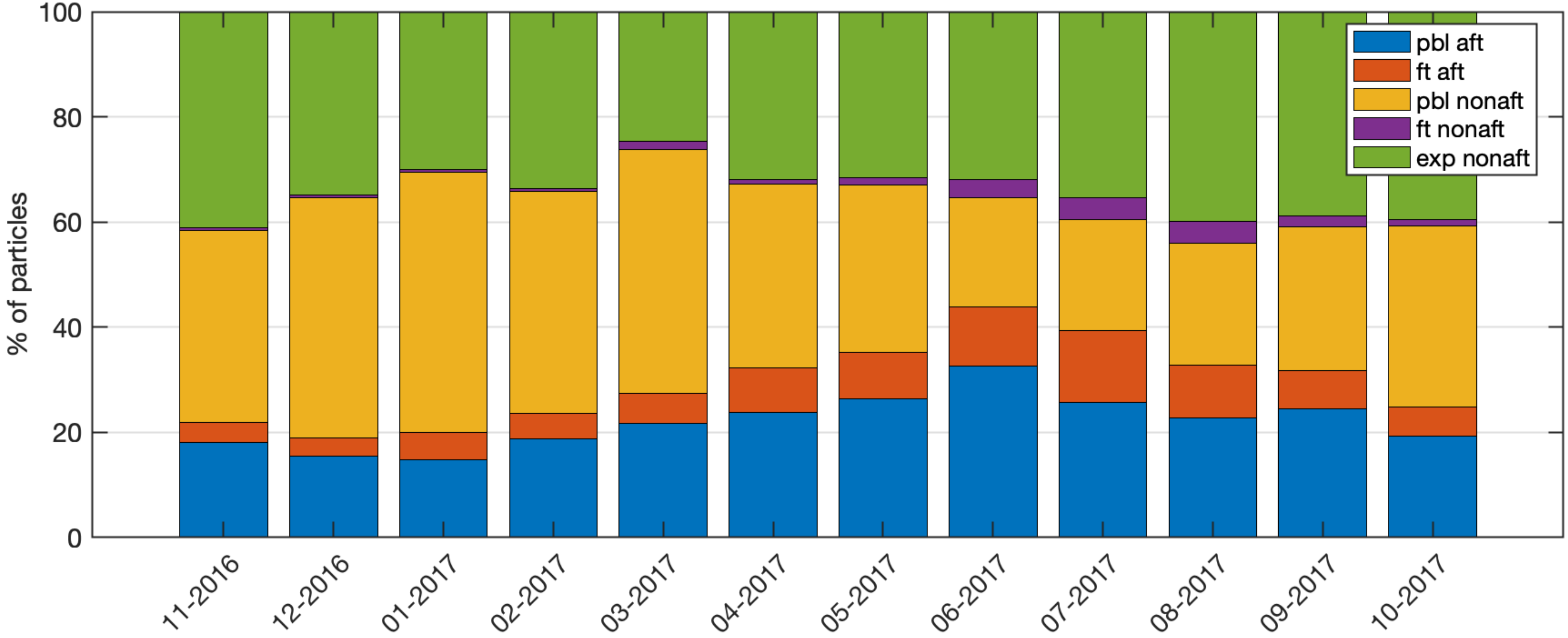
What did we learn?

- In the Washington/Baltimore area the background is variable in space and time.
- We must be careful in using upwind observations, especially for CO_2 in the growing season.
- Sampling vertical column above an upwind site performs well without requiring knowledge of any fluxes.
- Even in the best-case scenario, there is a lot of uncertainty/error in the background.
- Best choice may be to use an ensemble of independent background options when we can, because that gives us an idea of the uncertainty.

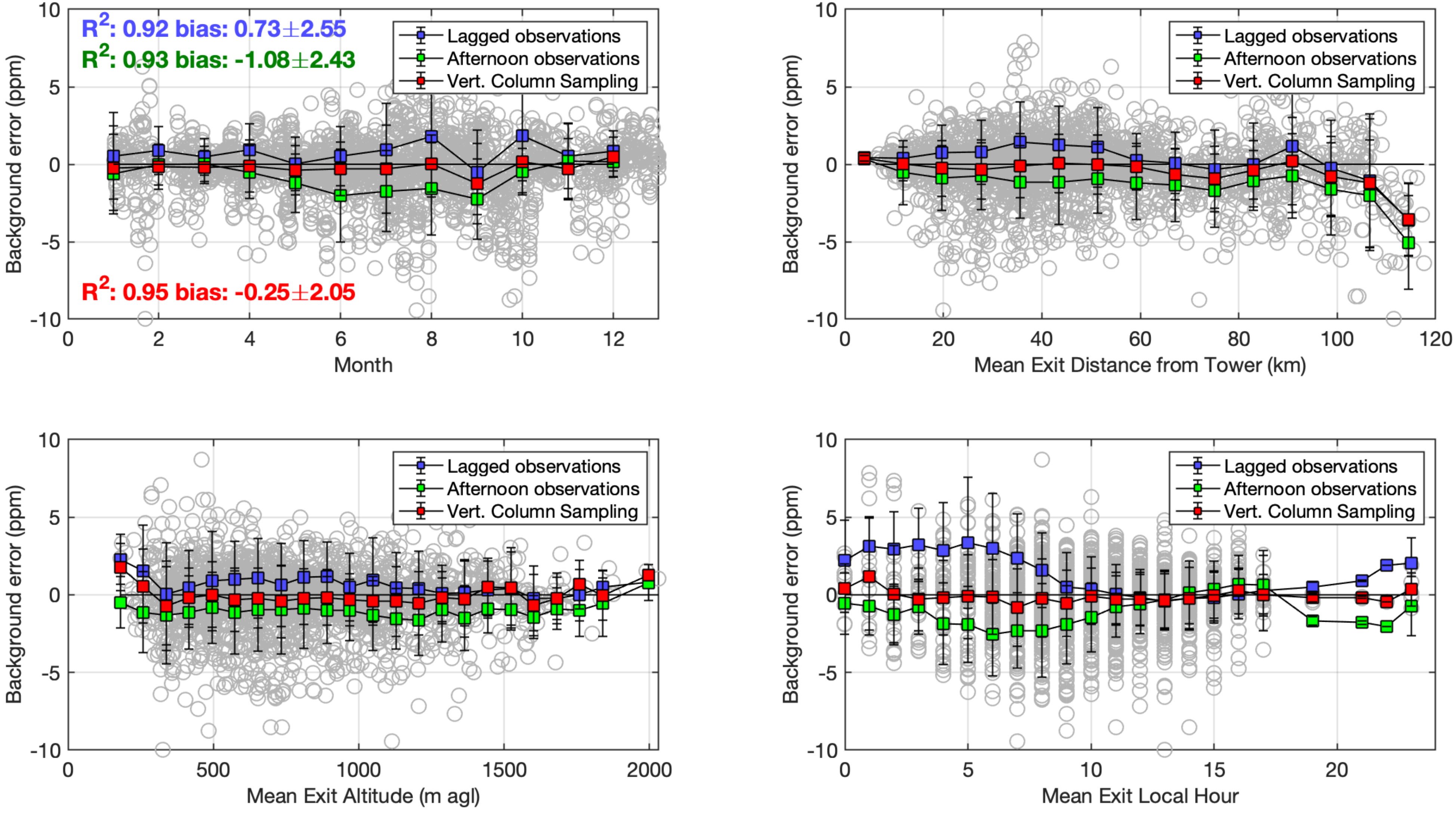
Uncertainty: use spread of backgrounds?



Where do particles exit? (altitude)



CO_2 (OSSE result) error/bias (Estimate – Truth)



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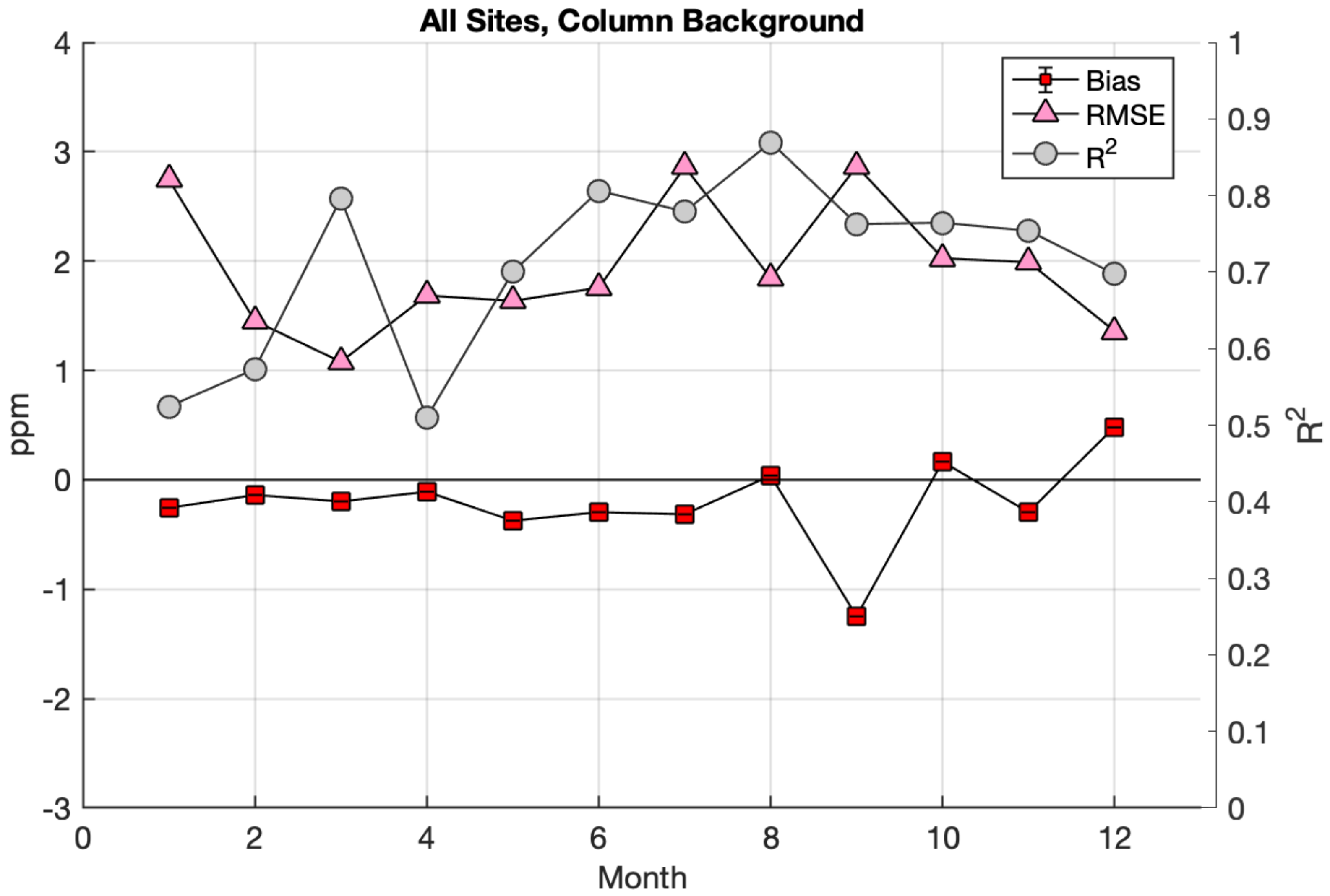
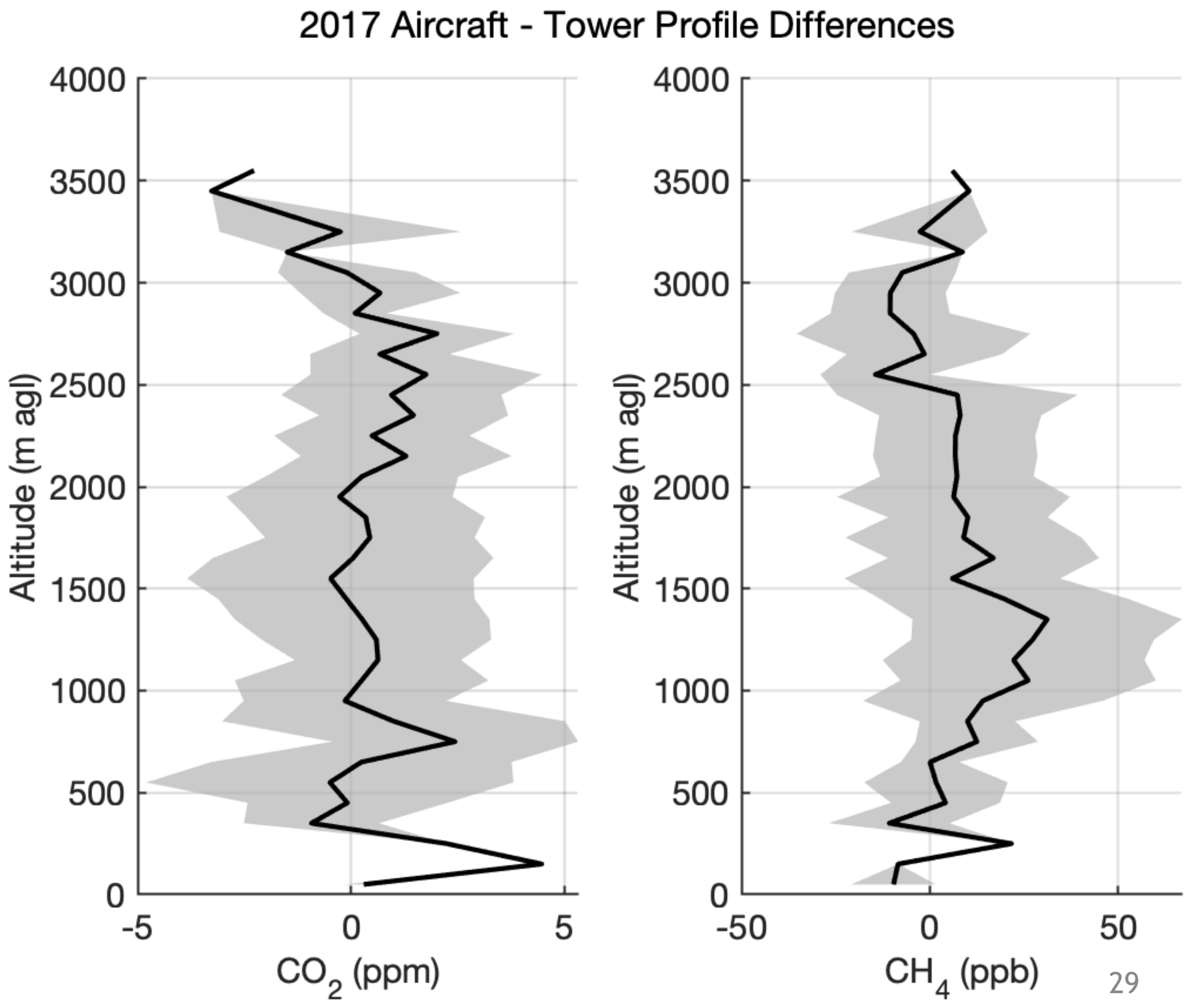
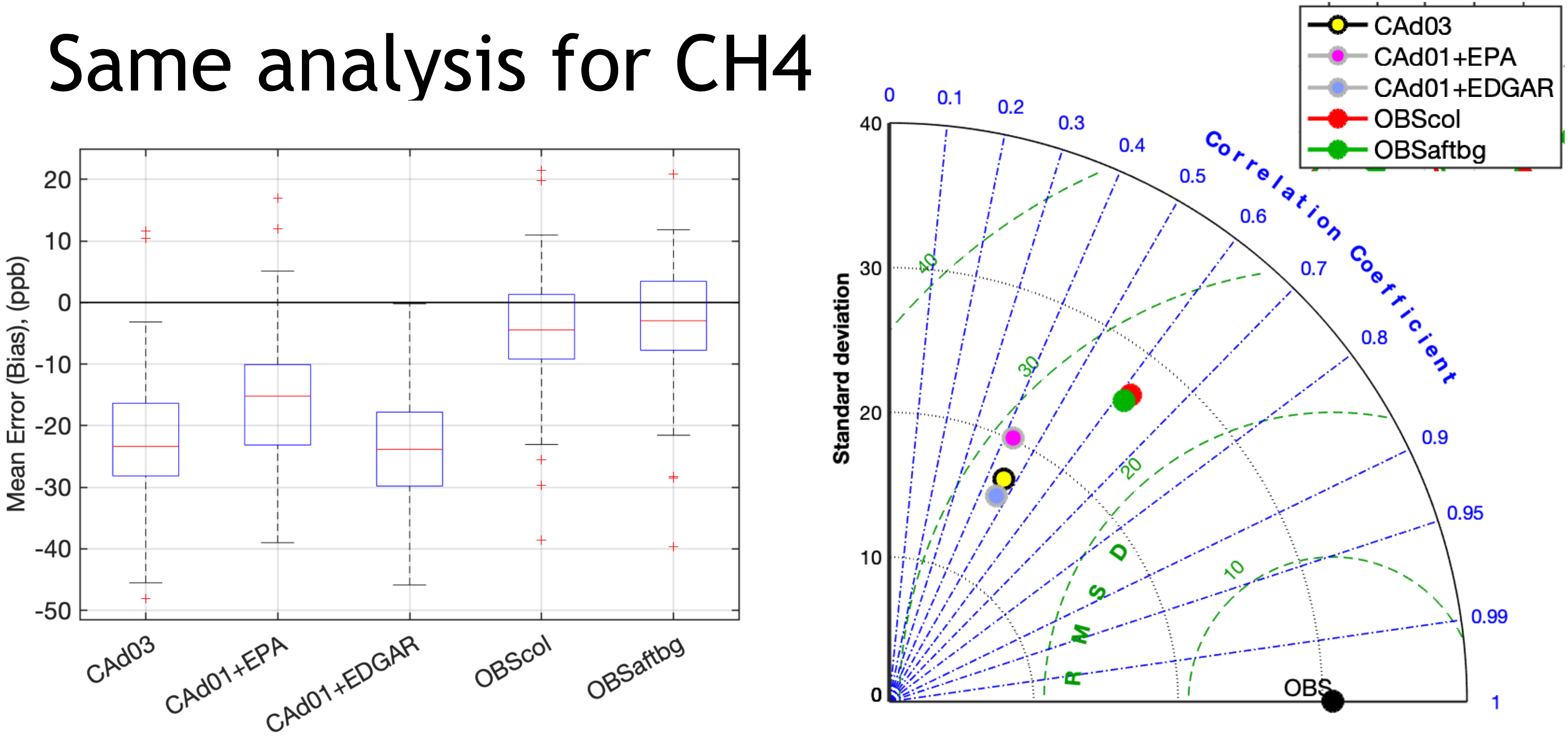


Comparison w/ flights

- 12 flights in 2017
- Isolate individual vertical profiles, compare with the constructed vertical profile at the BG site closest to the profile.
- Averaged all vertical profiles into altitude bins (100 m)
- Average the differences over multiple profiles and then multiple flight days.
- Figure shows mean difference +/- 1-sigma
- Profiles may not have been close to the site, so values within the PBL are expected to have higher residuals.

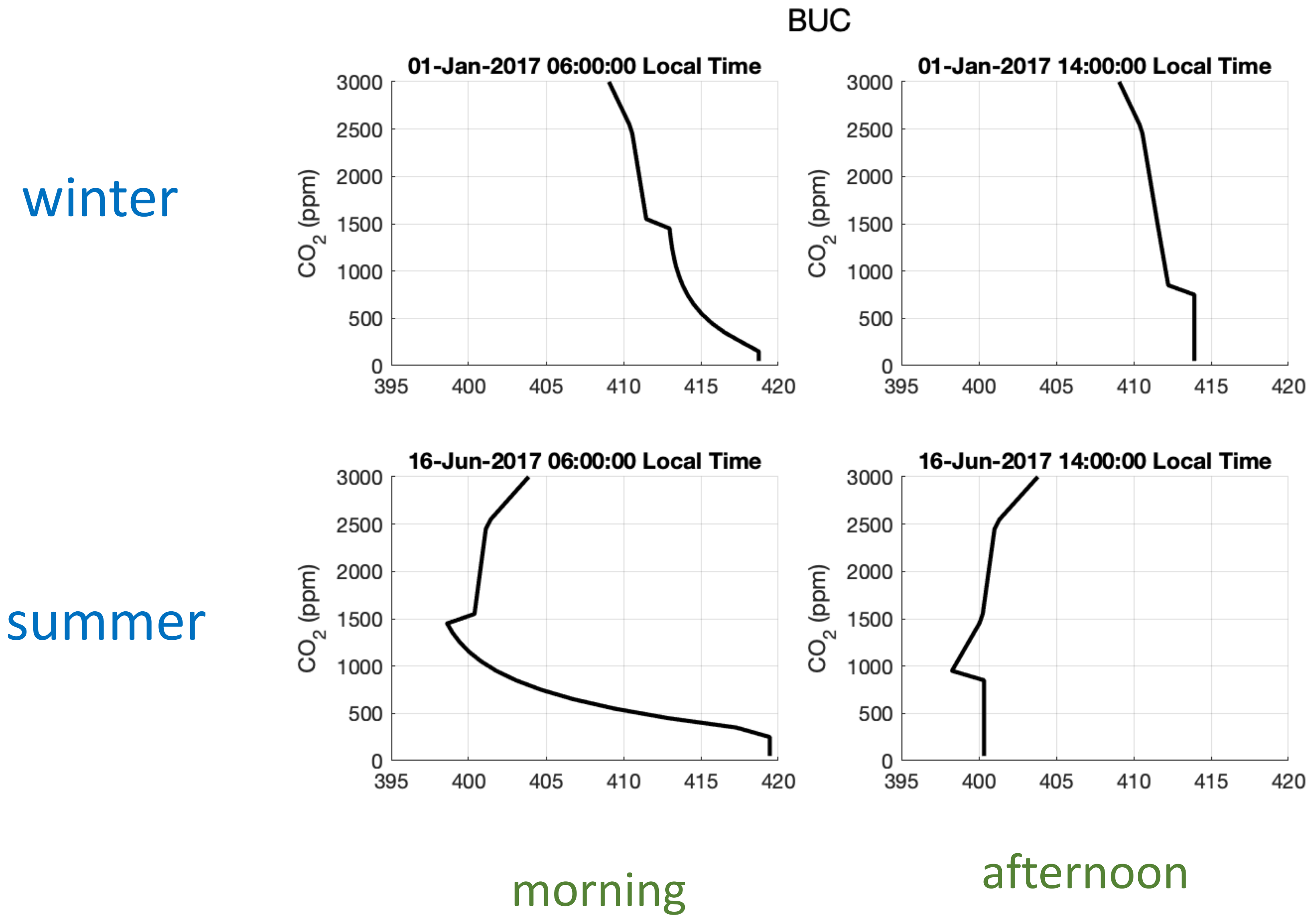


Same analysis for CH4

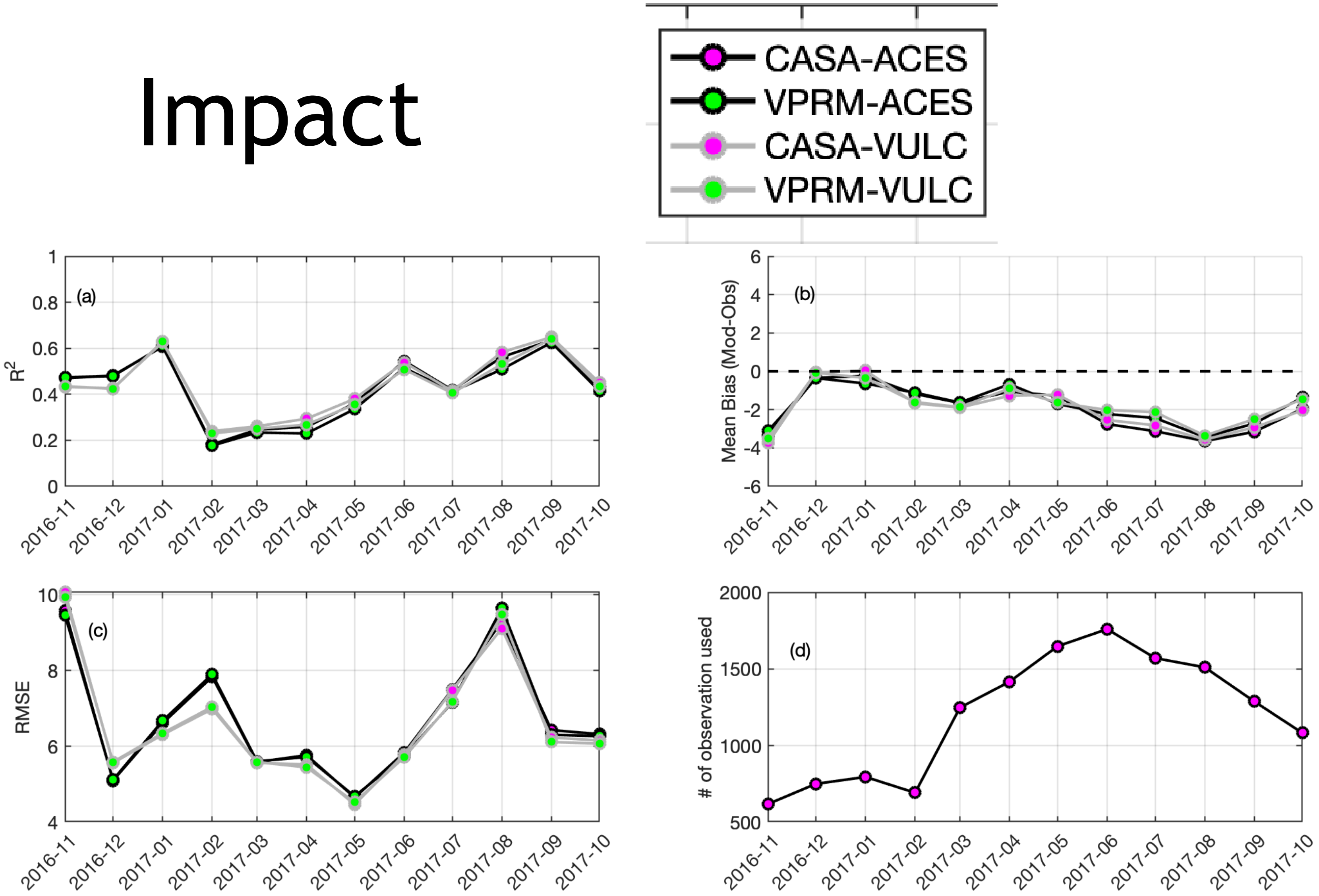


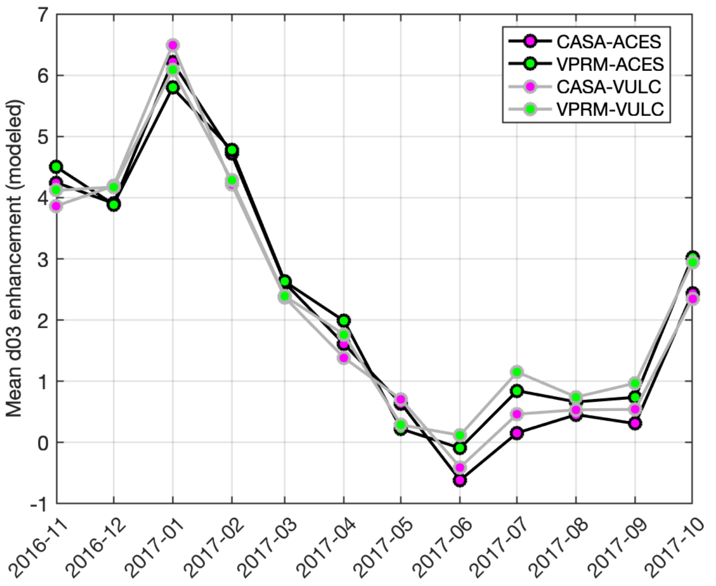
Observational background greatly outperforms models – because upwind fluxes are not well-known!

Examples of constructed background (BUC)



Impact

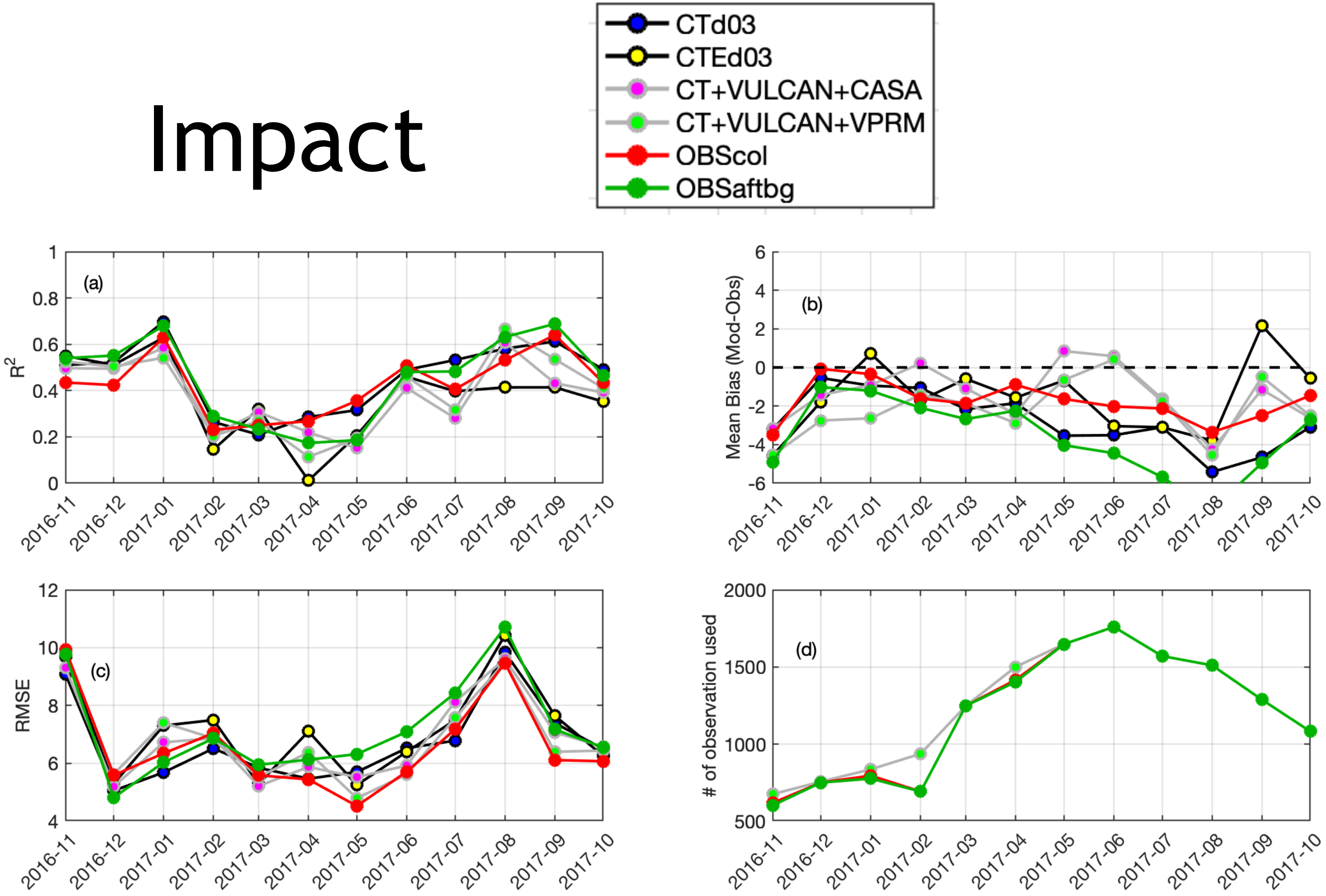




Modeled enhancement for different d03 flux combinations.

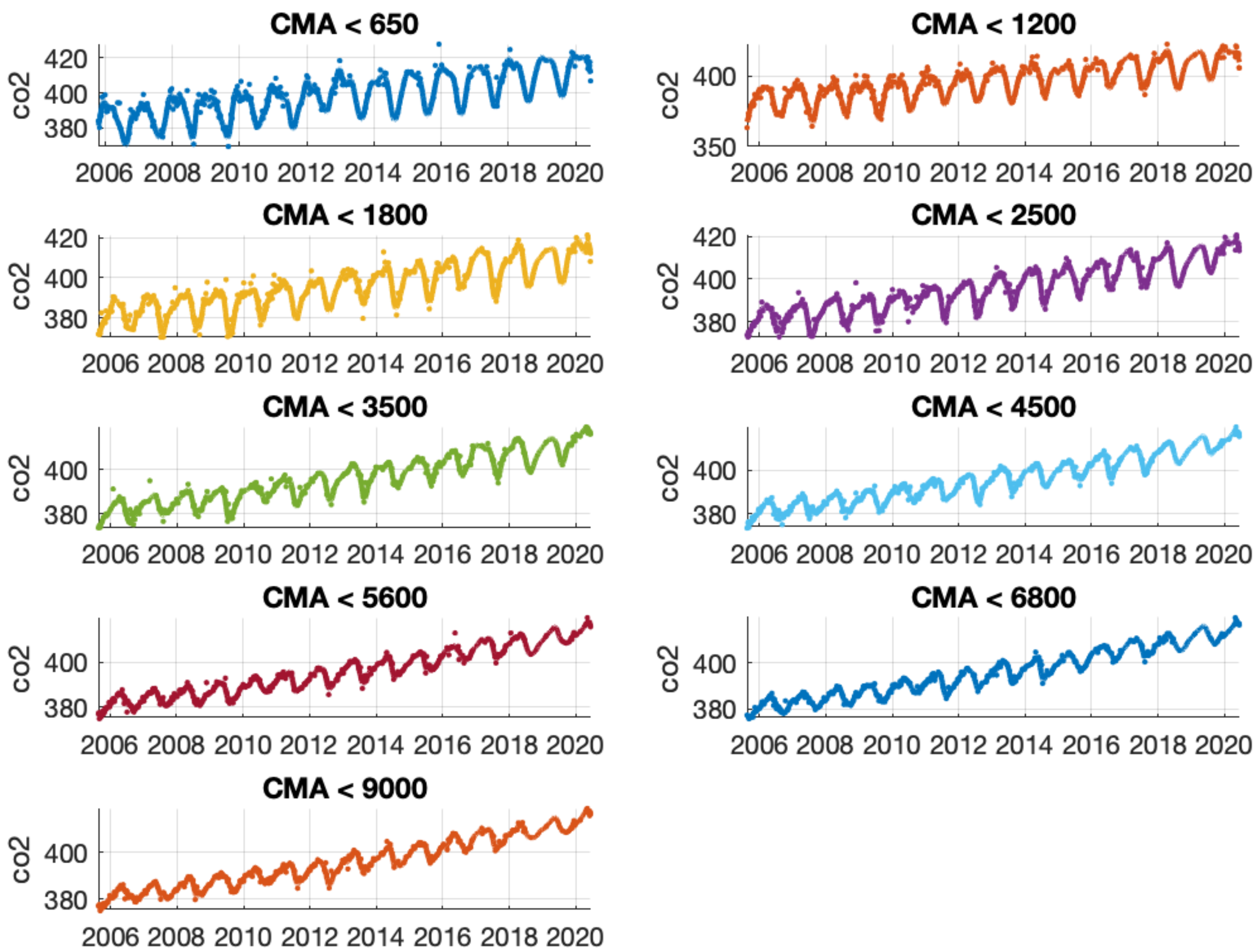
Model-obs comparison: Model is column-obs background + d03 fluxes.

Impact

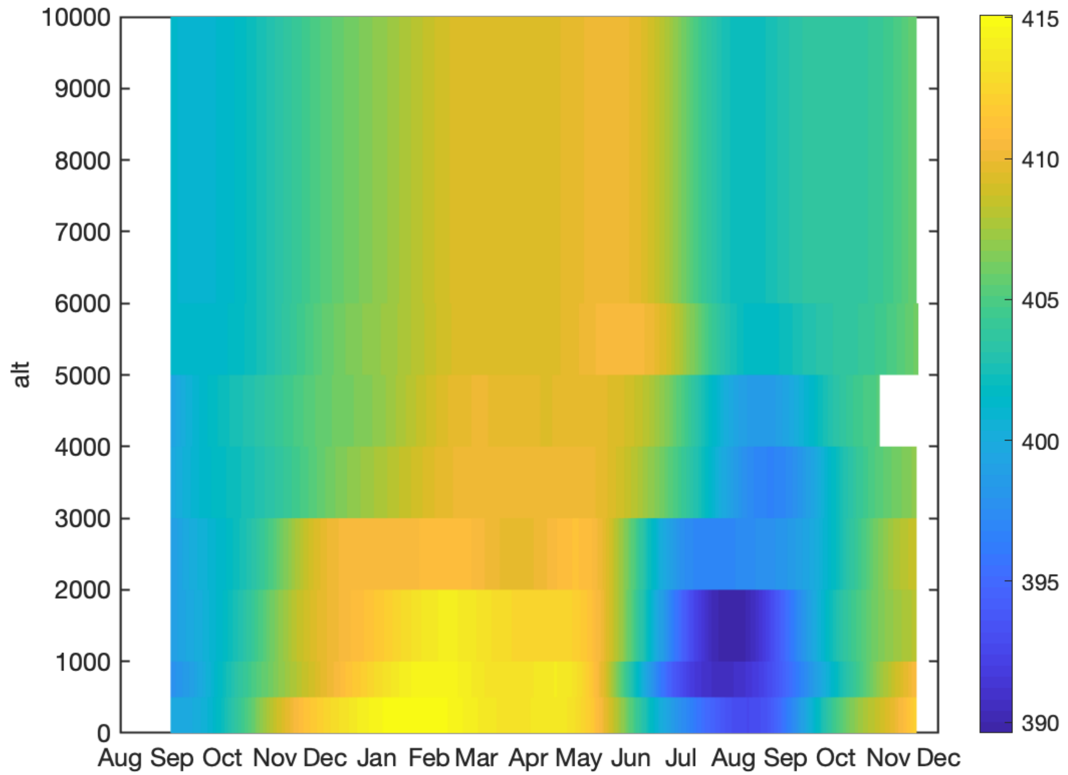


Choice of BG makes a much bigger impact than choice of d03 fluxes!!

Model-obs comparison: Model is various BG options + VPRM+VULCAN in d03.



NOAA Aircraft Flask Samples @ Cape May, NJ



Ccgcrv with 3 polynomials, 4 harmonics

cma_lon = -74.320
cma_lat = 38.830