Terrestrial CO_2 fluxes, concentrations, and budgets in USA and Northeast China

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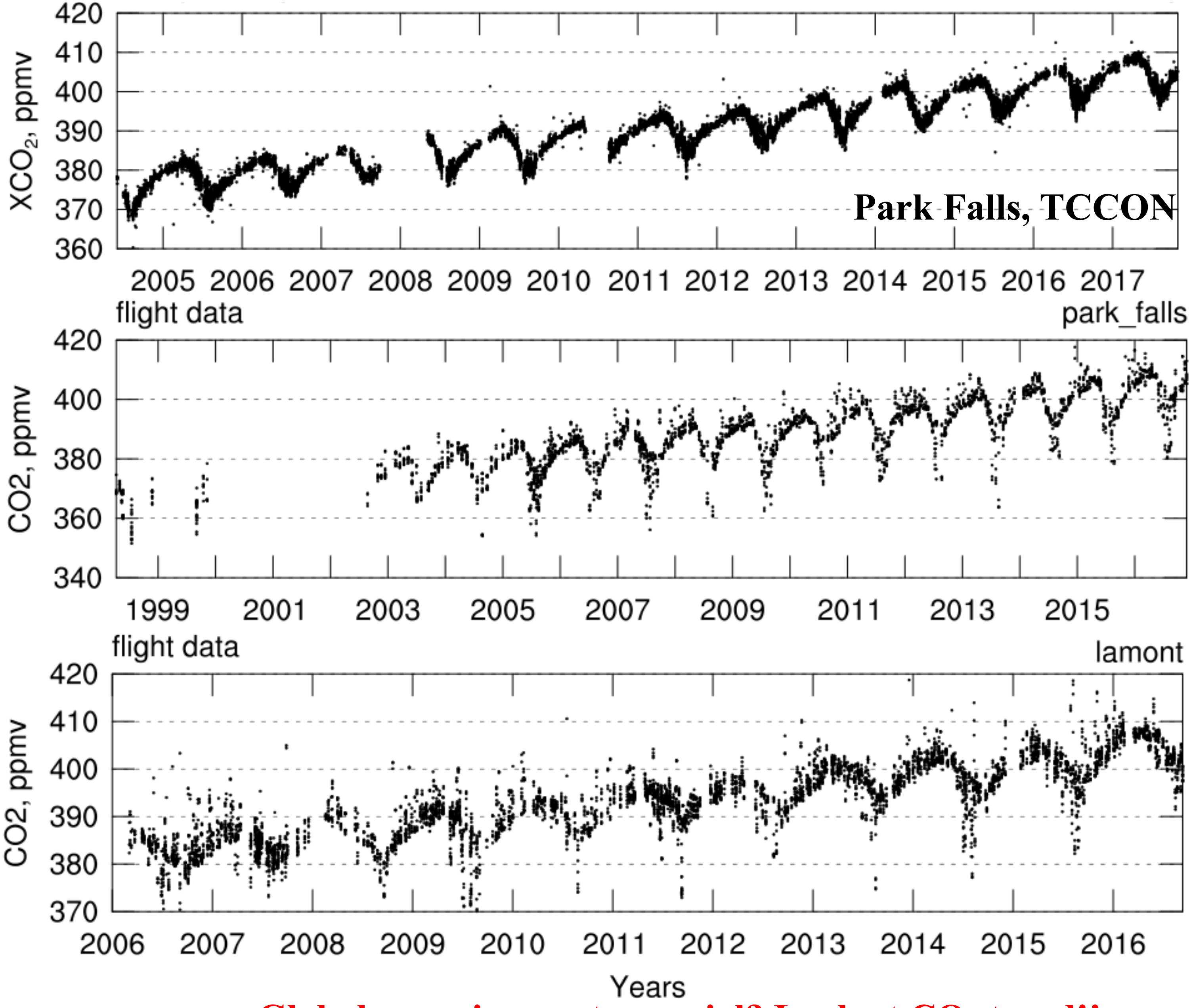
CO_2-induced global warming?

Trend of CO_2

Remote sensing

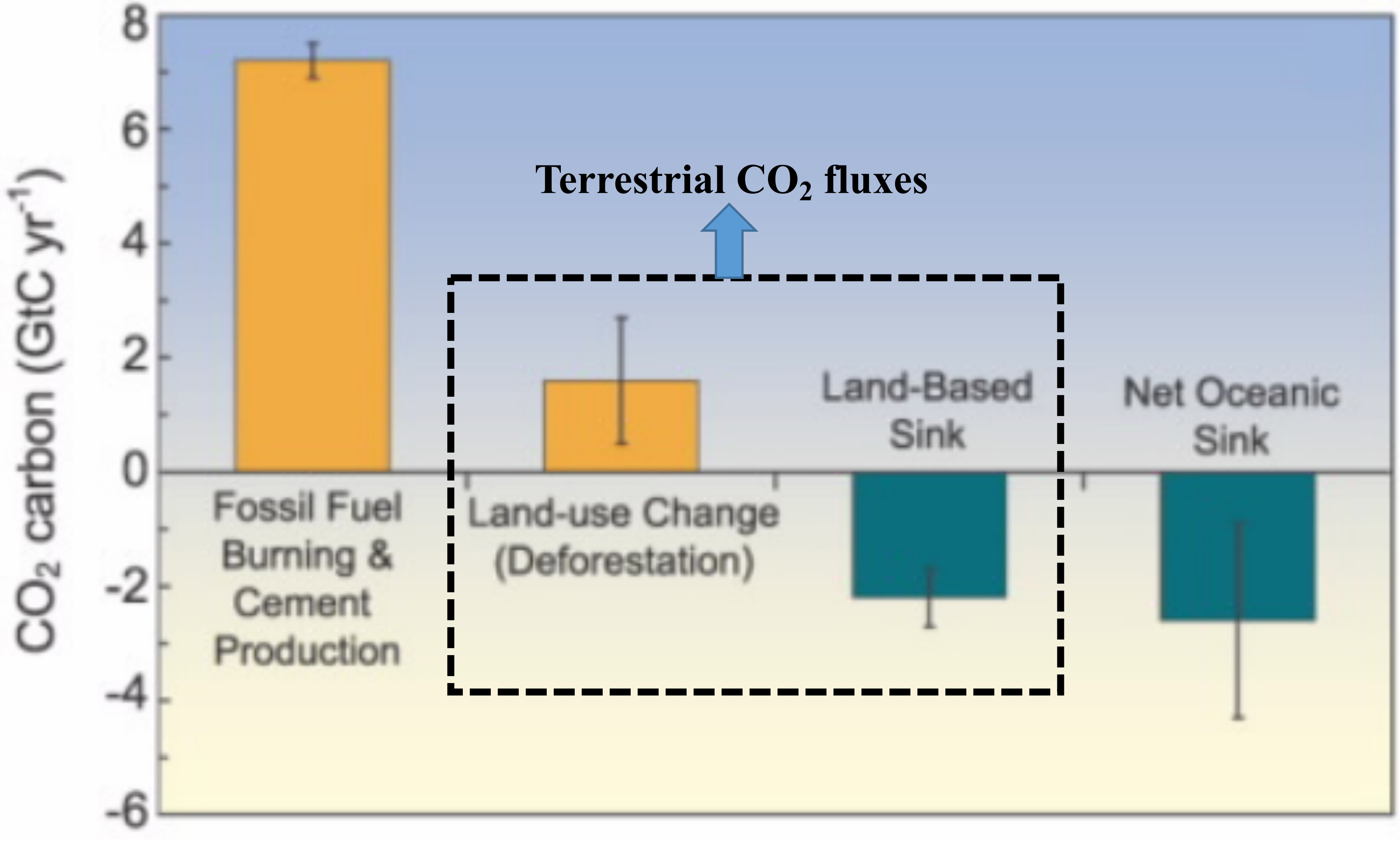
In situ

In situ



Global warming controversial? Look at CO_2 trend!!

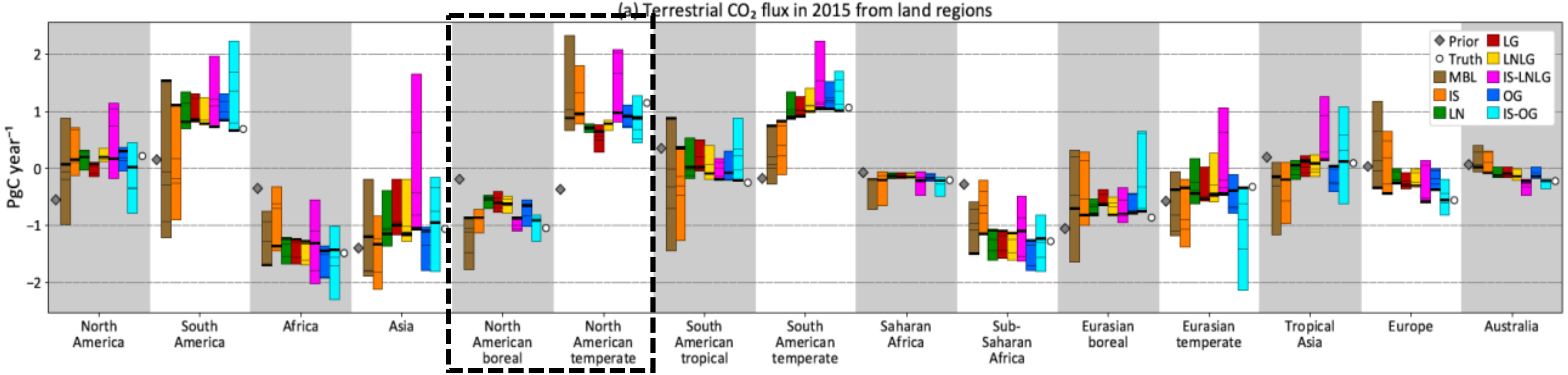
Global CO_2 sources and sinks



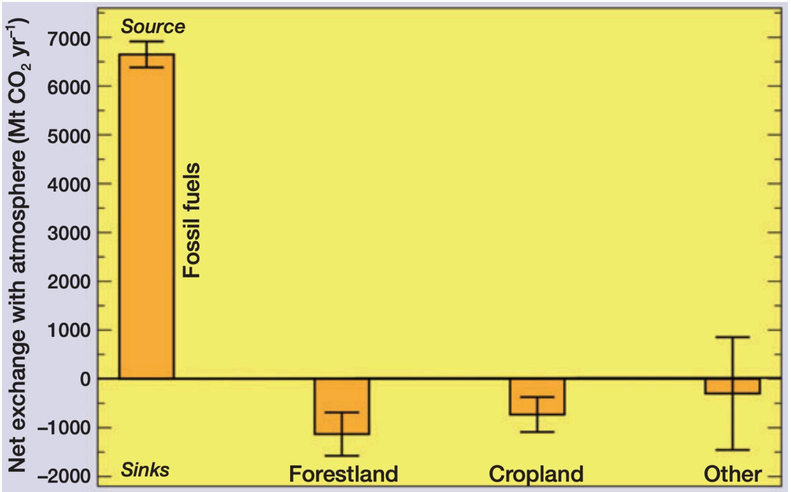
IPCC (2007)

Uncertainties of terrestrial CO_2 fluxes are large

Terrestrial CO_2 fluxes in different regions



(Sourish Basu et al., 2018)

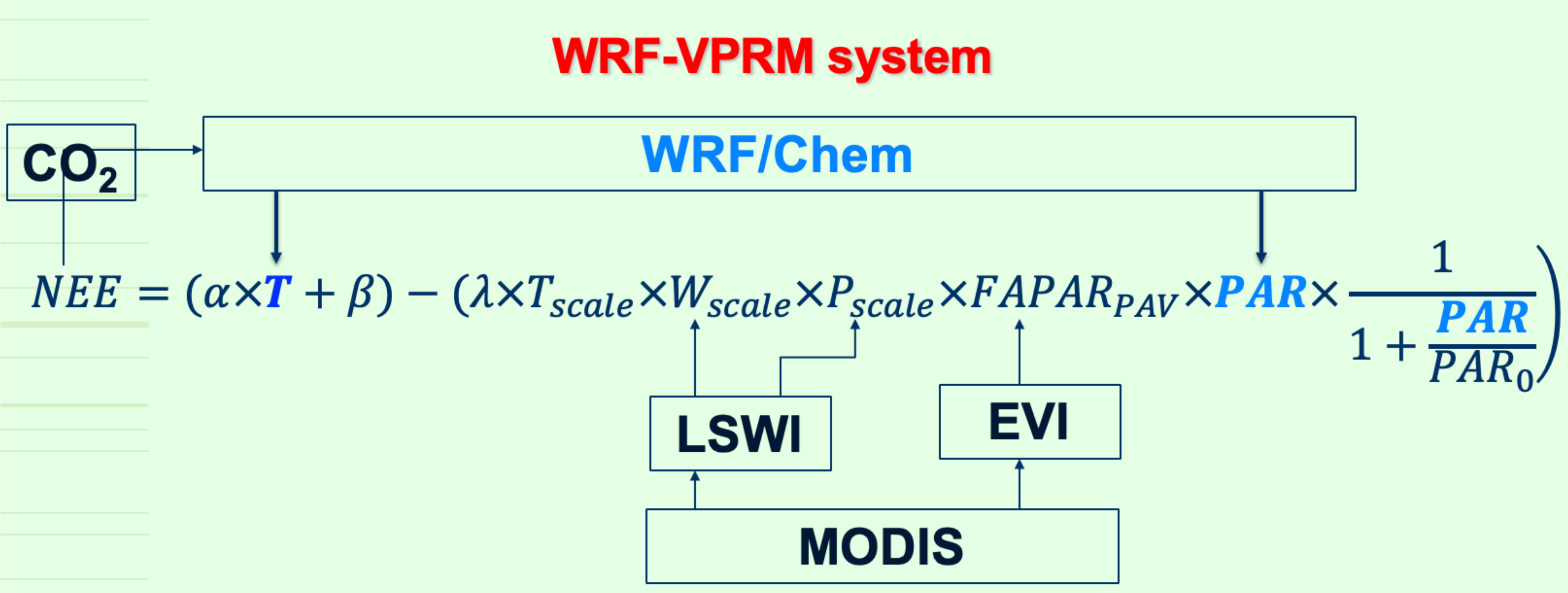


King et al., 2012 *North American CO_2 sources and sinks, circa 2010. The fossi*

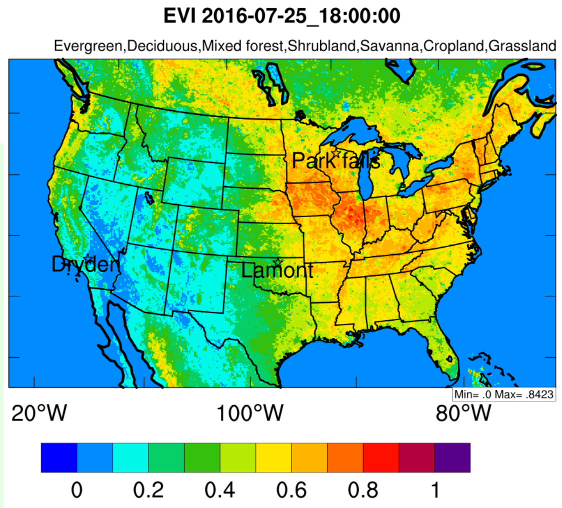
Uncertainties in each region are large too

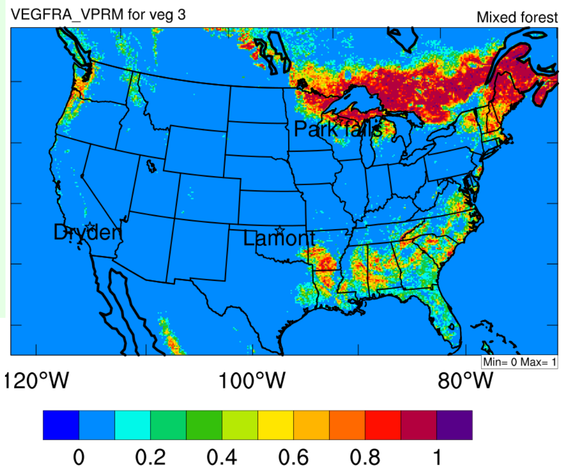
WRF/Chem-VPRM for CO_2 simulation

- Vegetation Photosynthesis and Respiration Model (VPRM) (Xiao et al., 2004; Mahadevan et al., 2008; Ahmadov et al., 2007)



$$NEE = (\alpha \times T + \beta) - \left(\lambda \times T_{scale} \times W_{scale} \times P_{scale} \times FAPAR_{PAV} \times PAR \times \frac{1}{1 + \frac{PAR}{PAR_0}}\right)$$





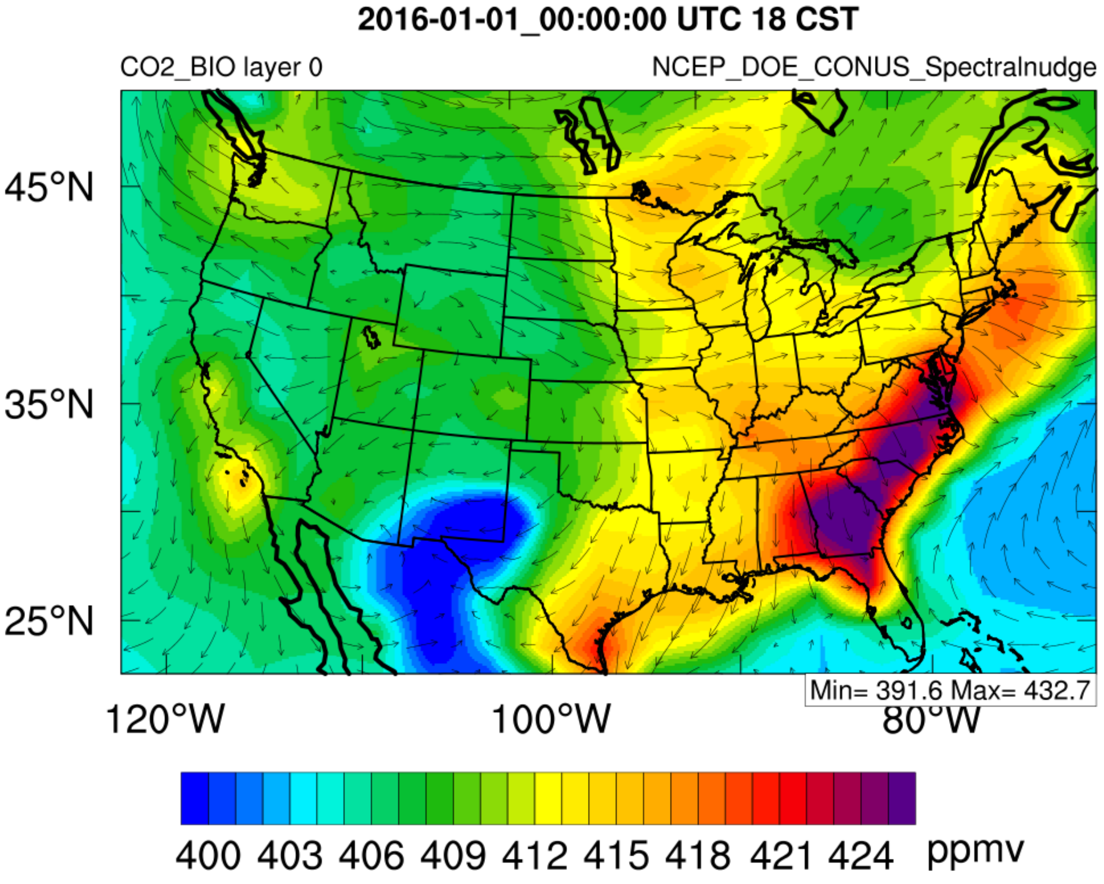
Implemented parameters from Hilton, Davis et al. (2013)

Calibrated using eddy covariance tower data over North America

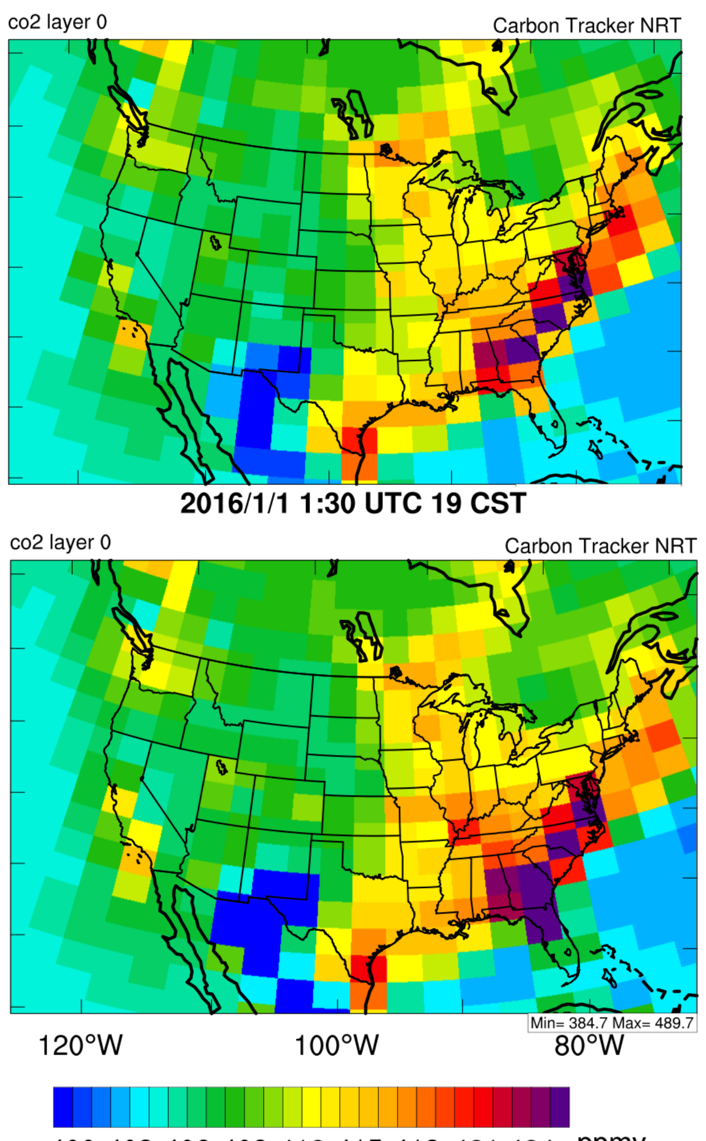
	Evergreen forest	Deciduous forest	Mixed forest	Shrub	Savanna	Crop	Grass
PAR_0	745.306	514.13	419.5	590.7	600	1074.9	717.1
λ	0.13	0.1	0.1	0.18	0.18	0.085	0.115
α	0.1247	0.092	0.2	0.0634	0.2	0.13	0.0515
β	0.2496	0.843	0.27248	0.2684	0.3376	0.542	-0.0986

And other minor changes to VPRM in WRF

Downscaling in year 2016 from CT-NRT.v2017



WRF-VPRM IC

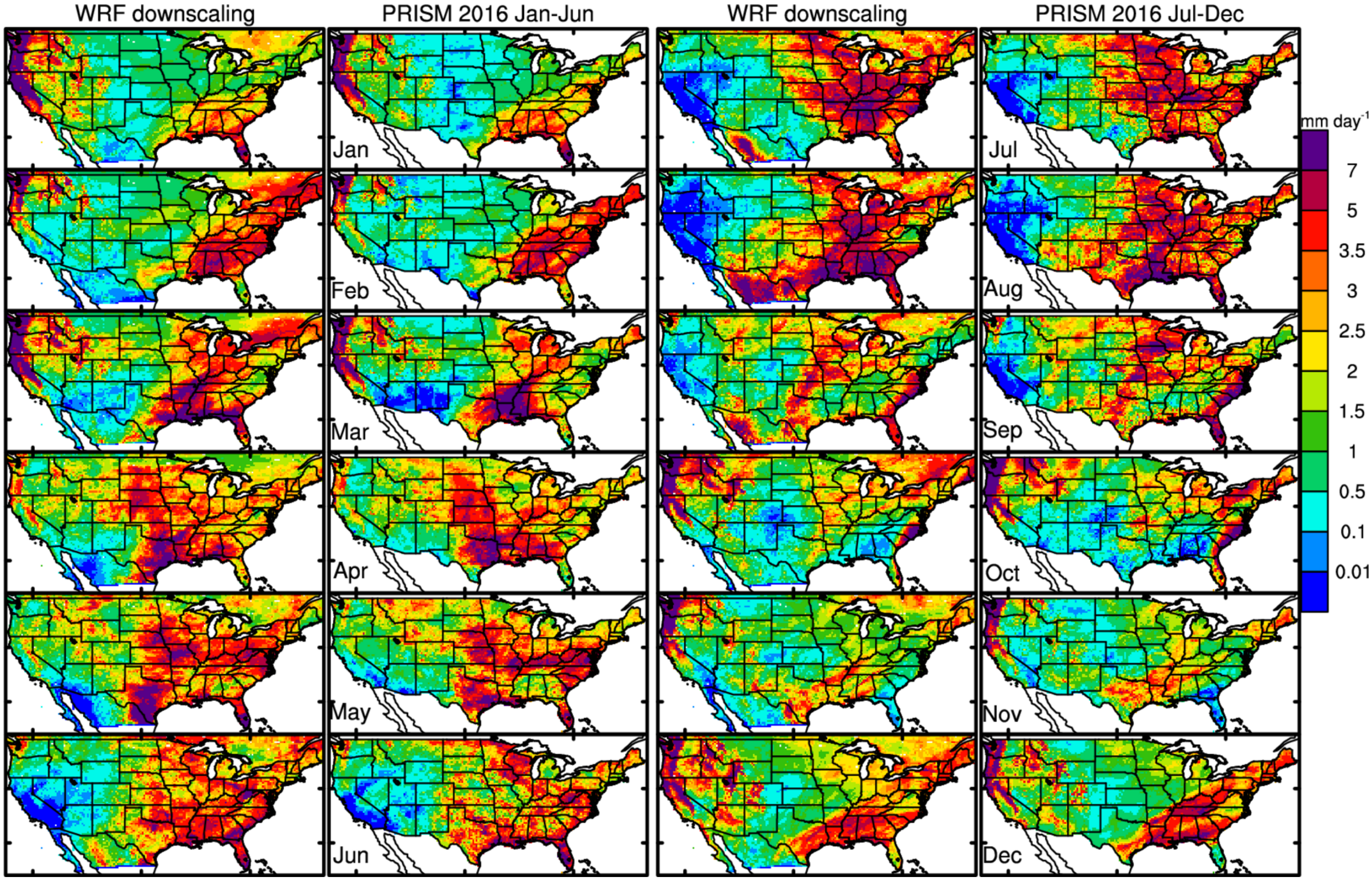


Point 1: both IC/BC are time dependent

Point 2: resolution of WRF-VPRM is much higher, adequate to investigate impact of weather

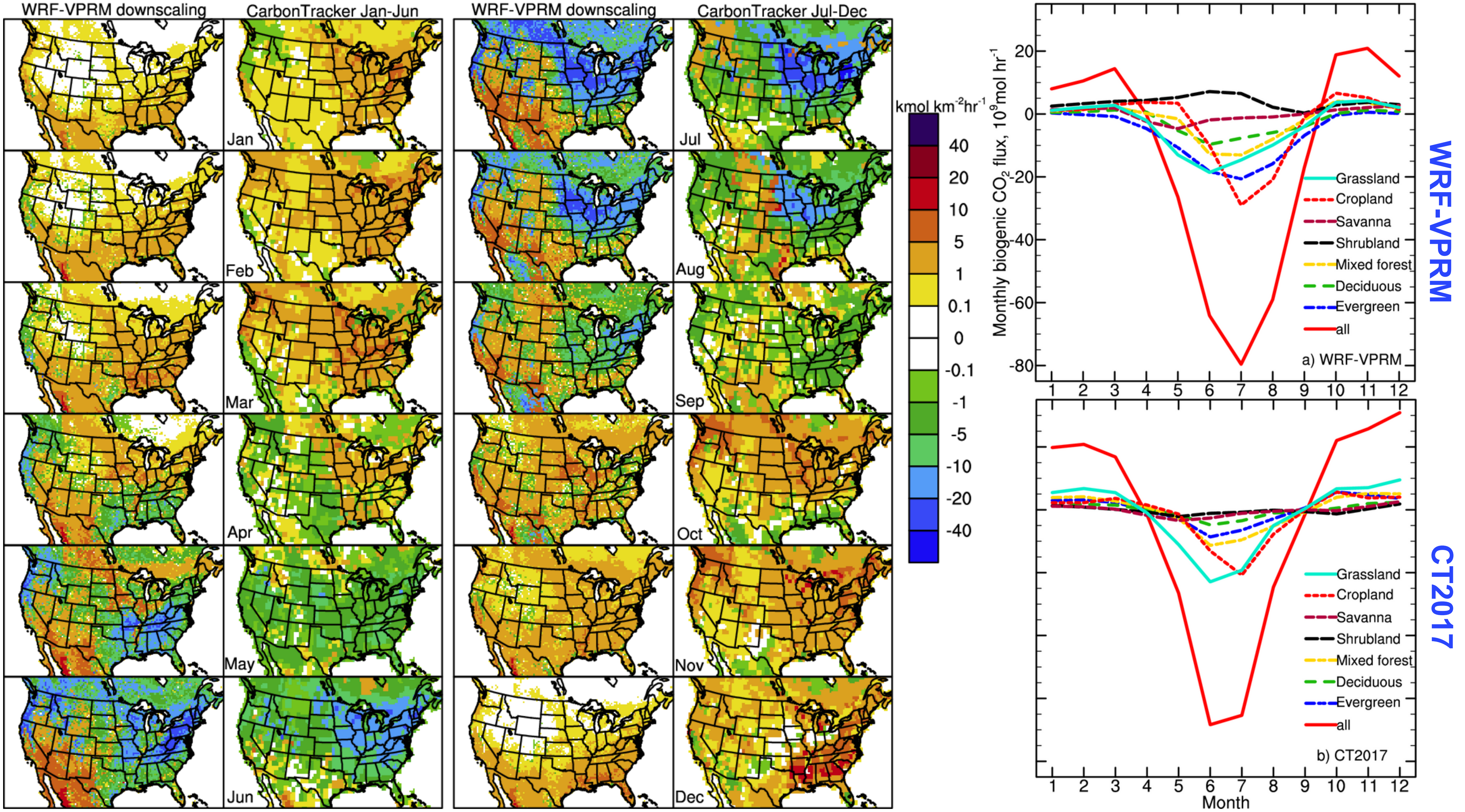
configuration for WRF-VPRM downscaling

Short wave radiation	Dudhia
Long wave radiation	rapid radiative transfer model (RRTM)
Boundary layer	YSU
Microphysics	Morrison
Cumulus	Grell-Freitas
Land surface model	NOAH
Vertical levels	47
Horizontal resolution	12 km $\times$ 12 km with 266$\times$443 grid points
Time step	60 seconds
Meteo initial and lateral boundary conditions	NCEP/DOE Reanalysis 2 (R2)
CO_2 initial and lateral boundary conditions	**CarbonTracker** global simulation 3°$\times$2° outputs
Interior nudging	**Spectral nudging**
nudging variables	horizontal wind components, temperature, geopotential
nudging coefficient	3×10^{-5} s^{-1}
nudging height	above PBL
wave number	5 and 3 in the zonal and meridional directions respectively
nudging period	throughout the downscaling simulation

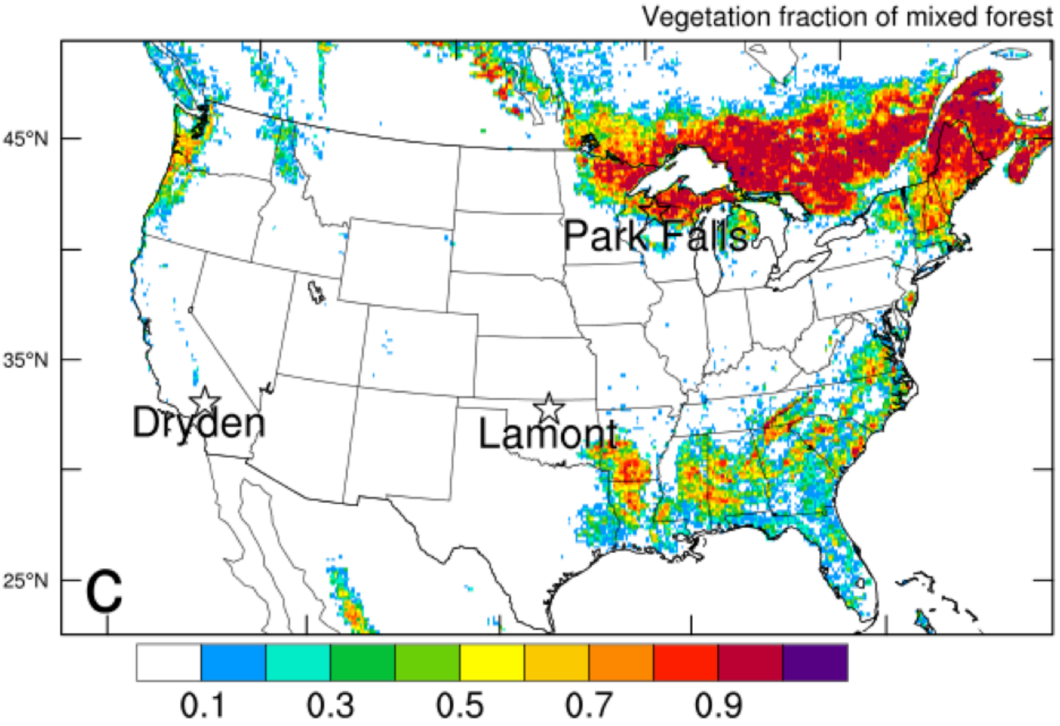


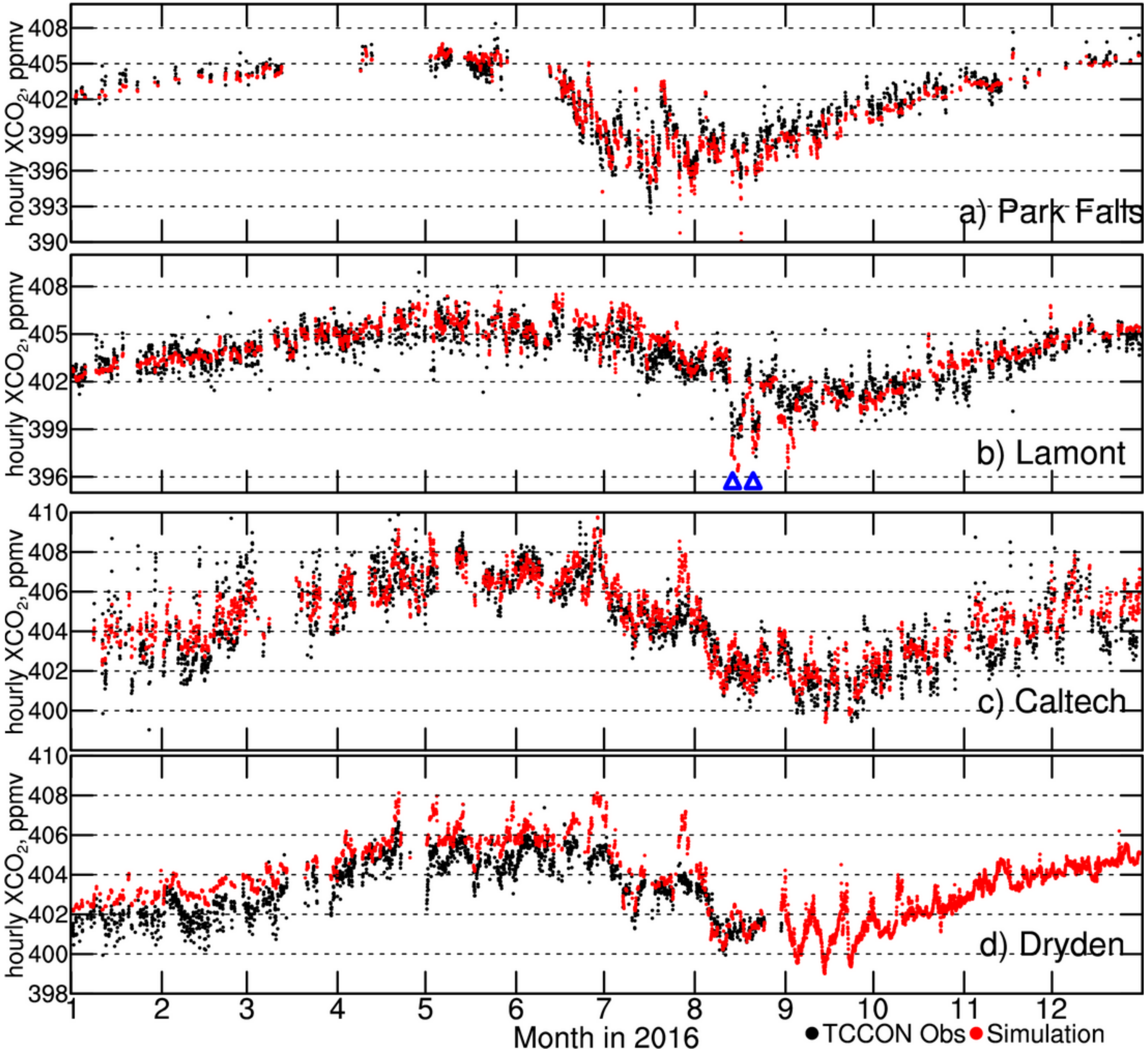
Downscaling captures the monthly variation of precipitation

Biogenic CO_2 fluxes downscaled by WRF-VPRM vs. CarbonTracker posterior fluxes



XCO_2 at the 4 TCCON sites

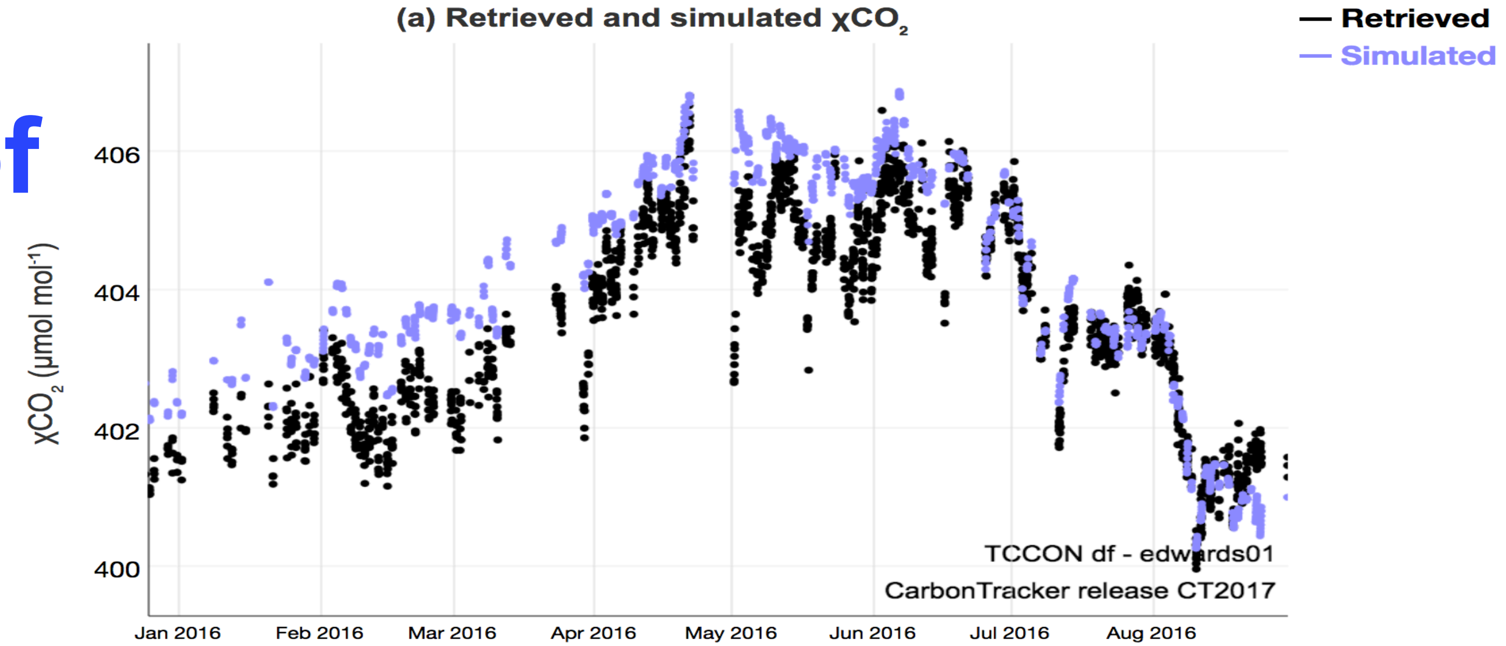




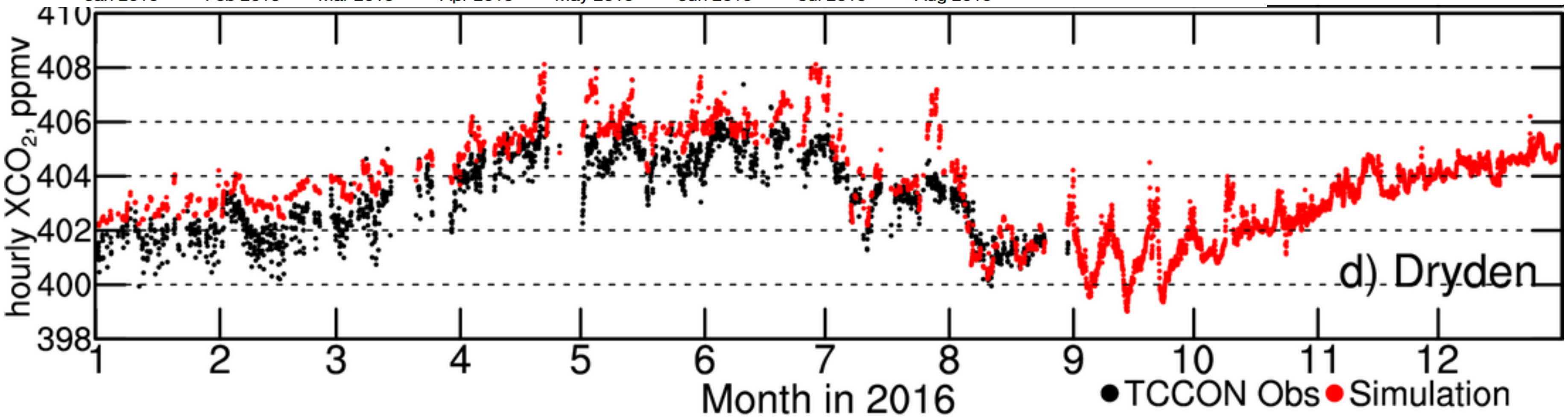
Bias in western boundary?
Bias in anthropogenic emission?

captures the seasonal and some episodic variation of XCO_2.

Evaluation of CT2017

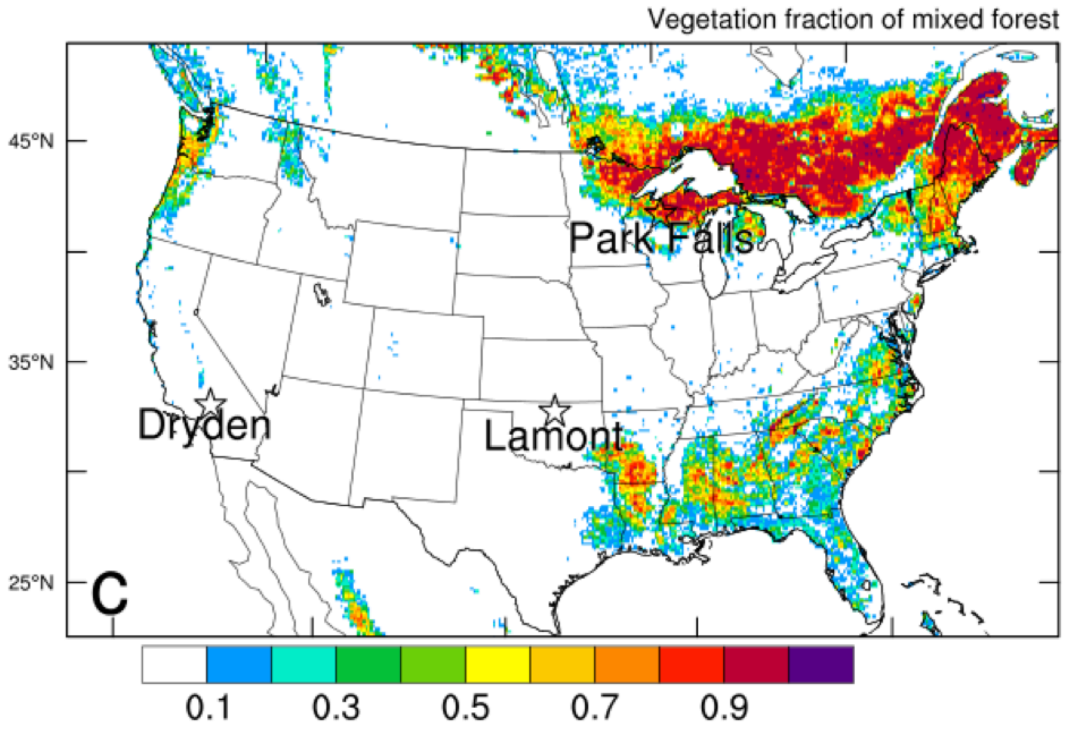


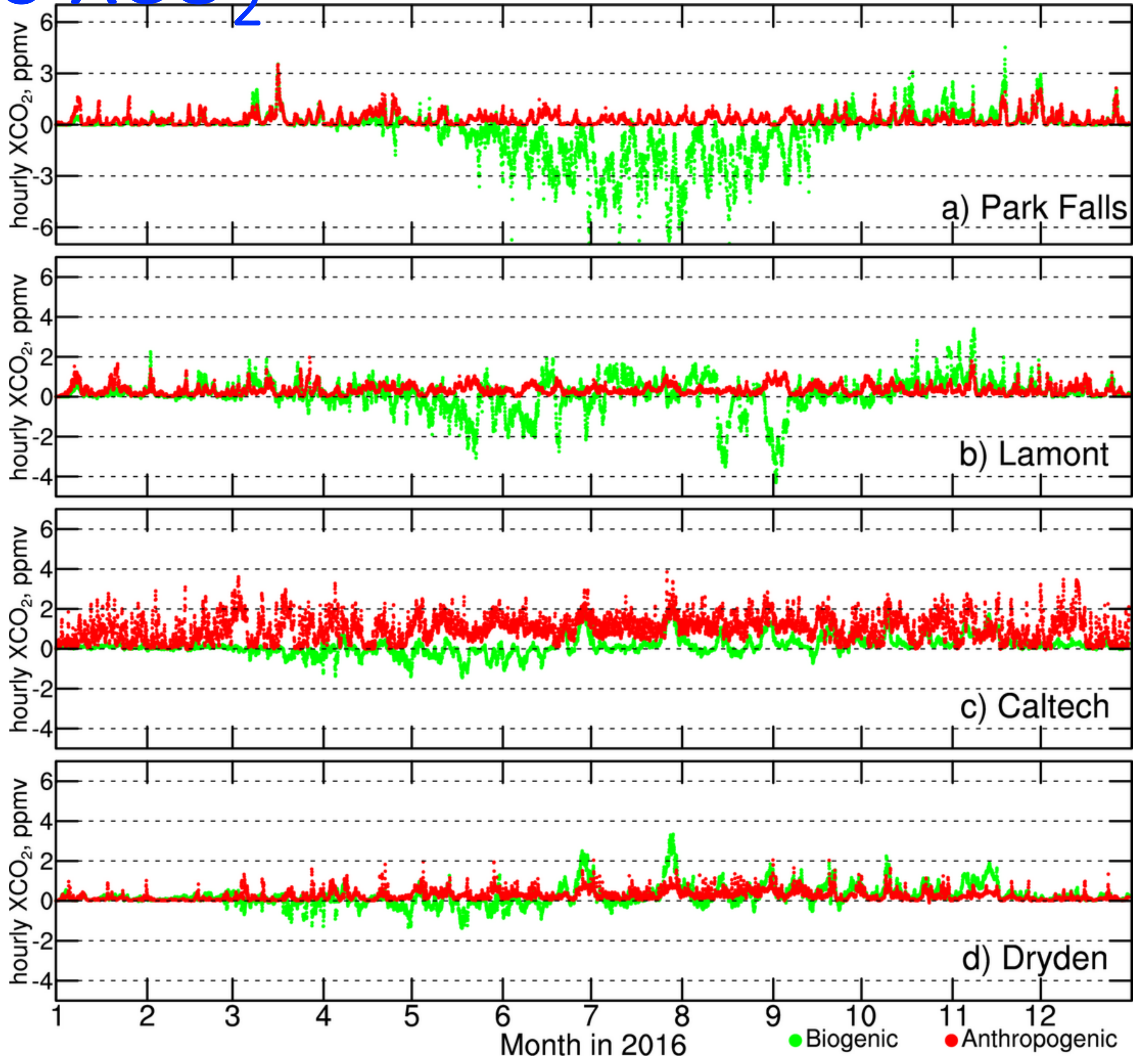
Evaluation of WRF-VPRM



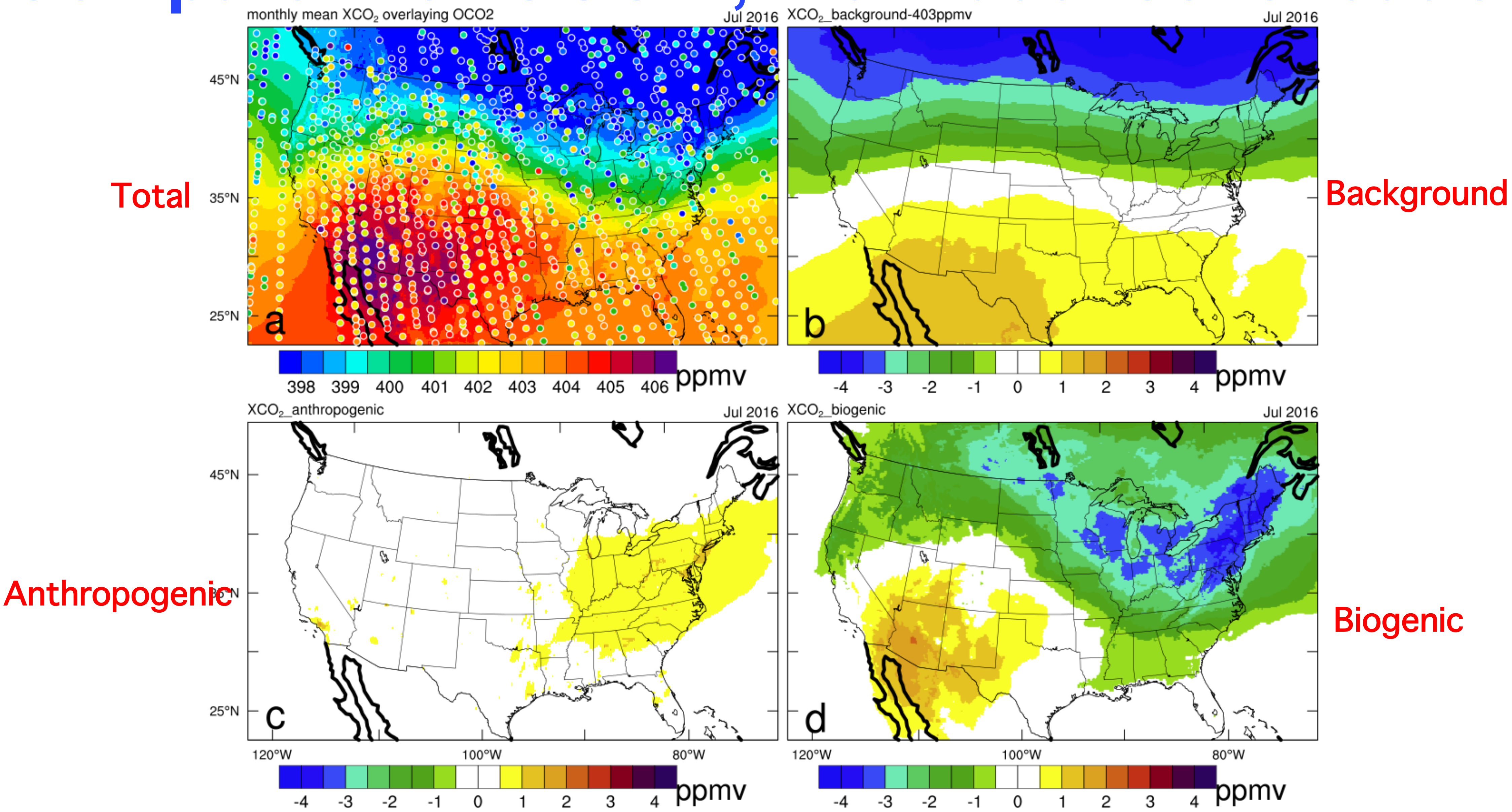
Thus, bias in western boundary partially contributed to WRF-VPRM bias?

Individual contribution to XCO_2

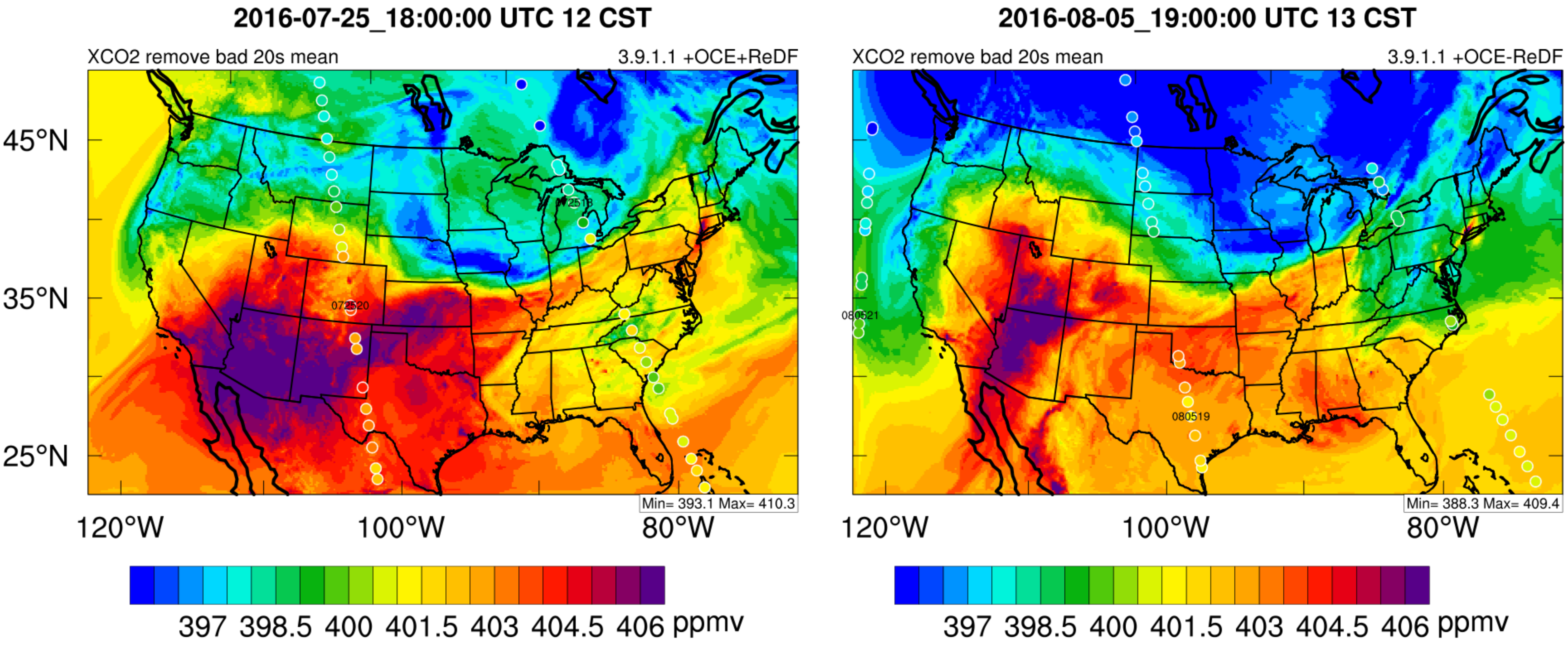




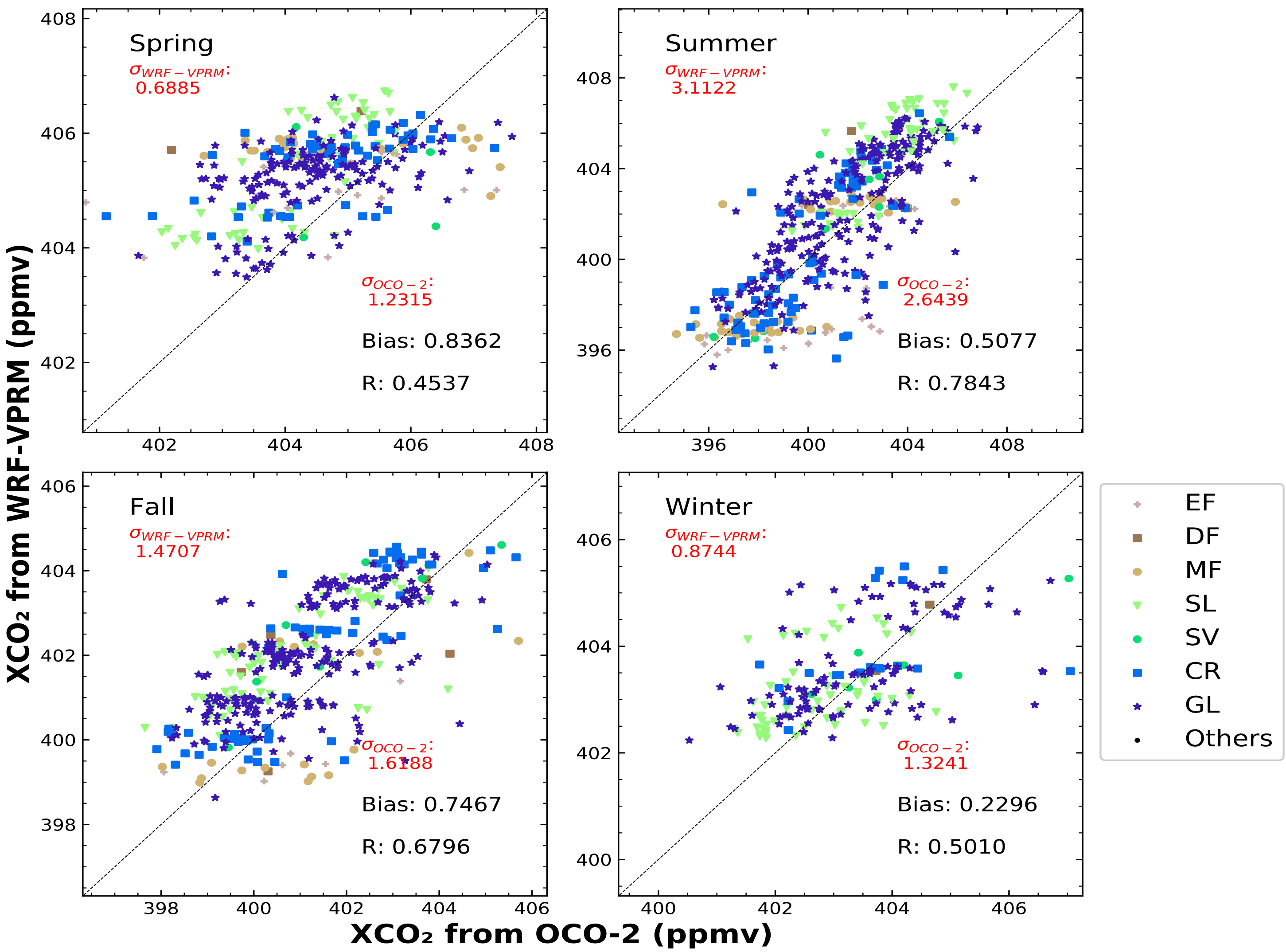
Compare with OCO-2; individual contributions



Compare with OCO-2, individual cases

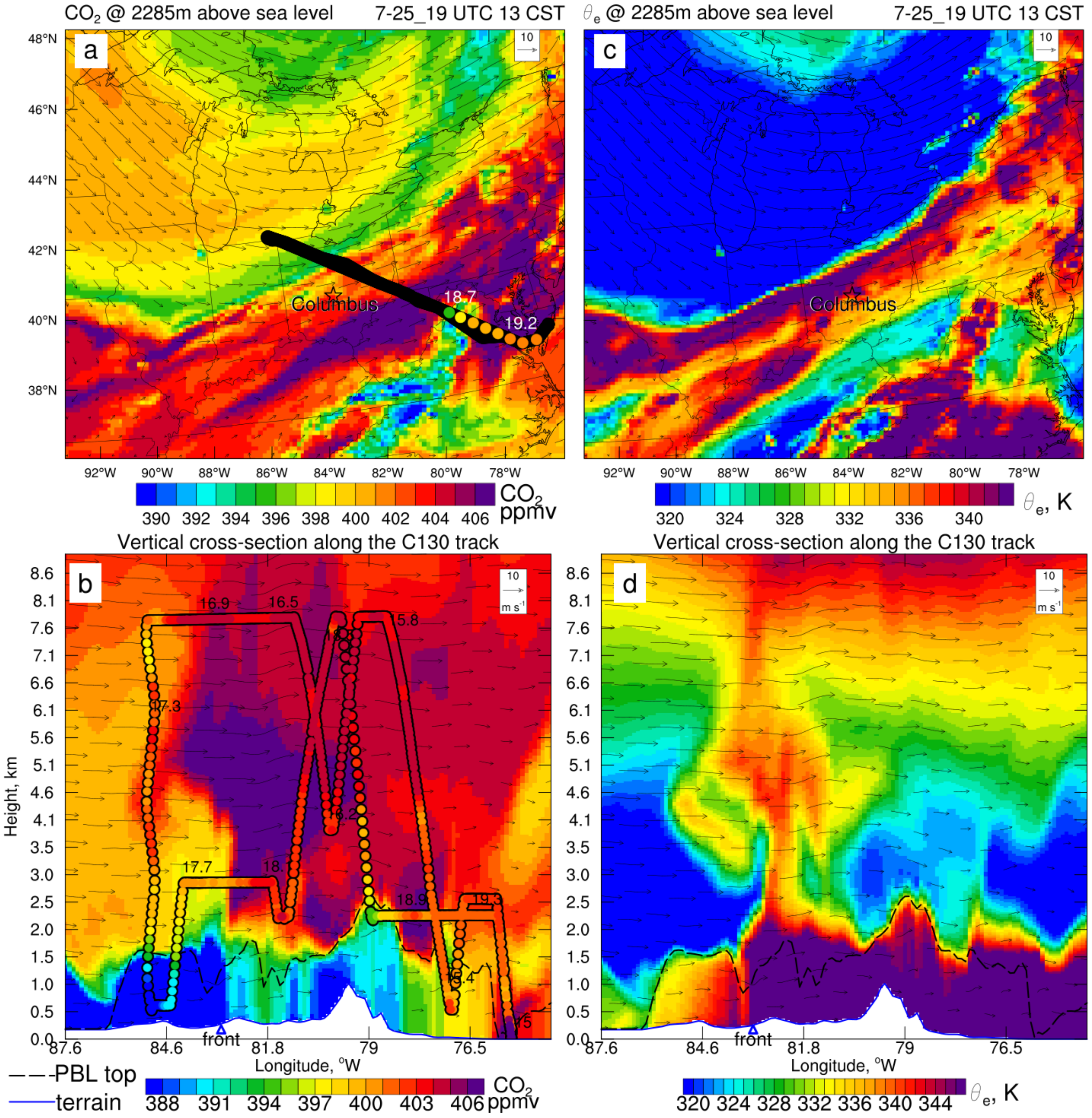


Statistic evaluation of XCO_2 using OCO-2 data



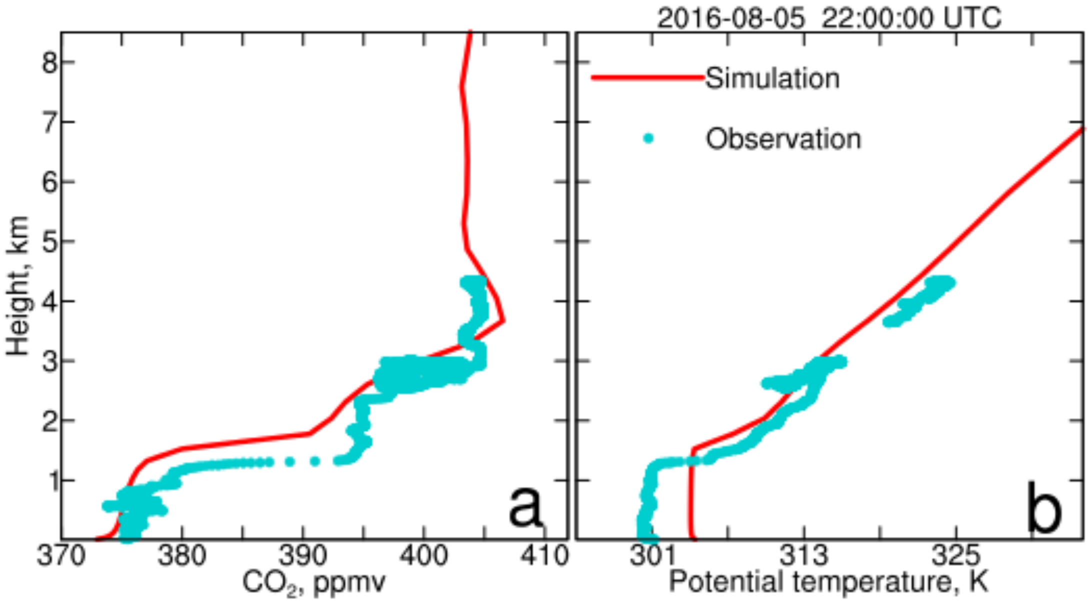
Best performance in Summer, followed by Fall

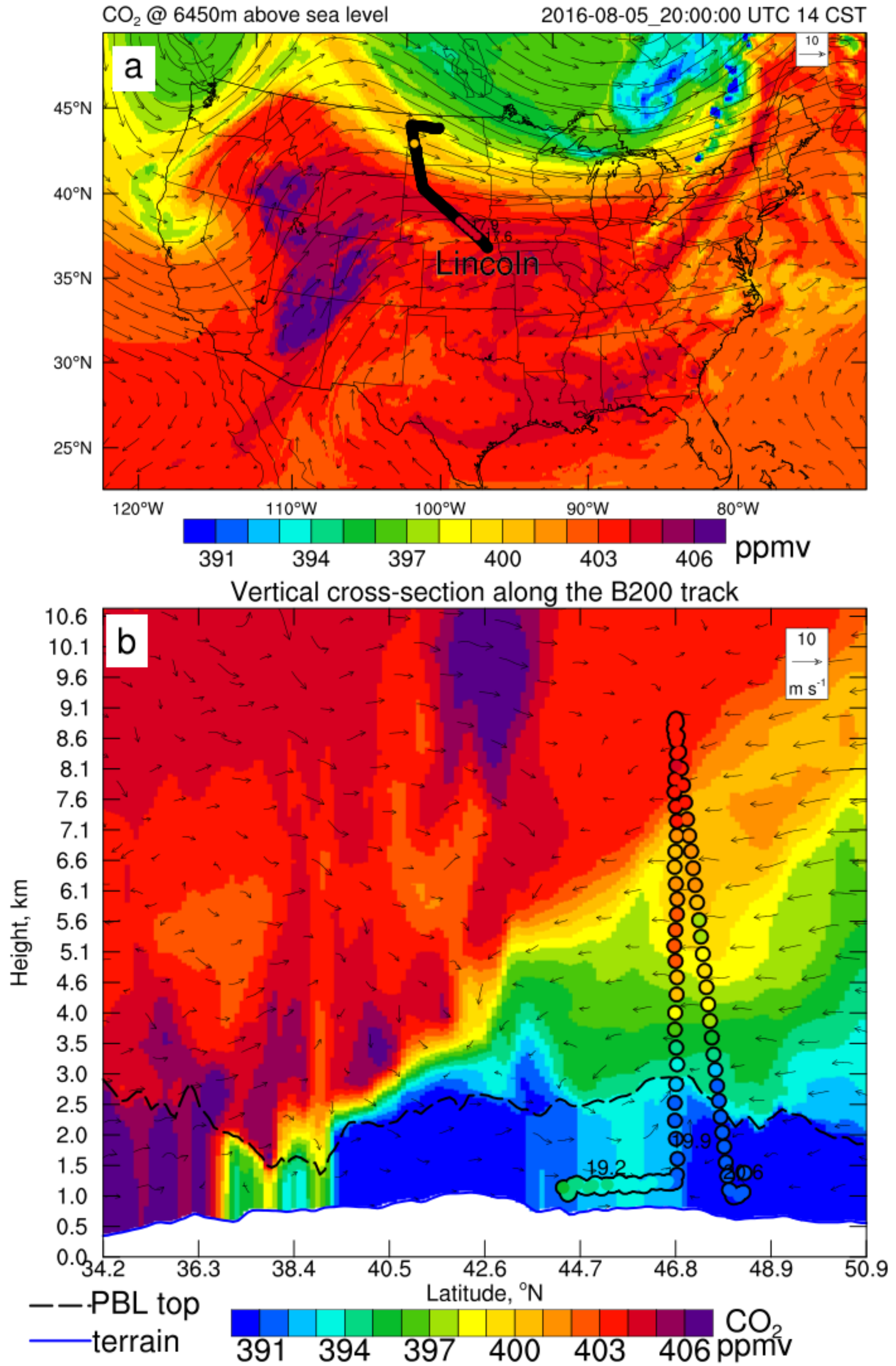
Case study
July 25



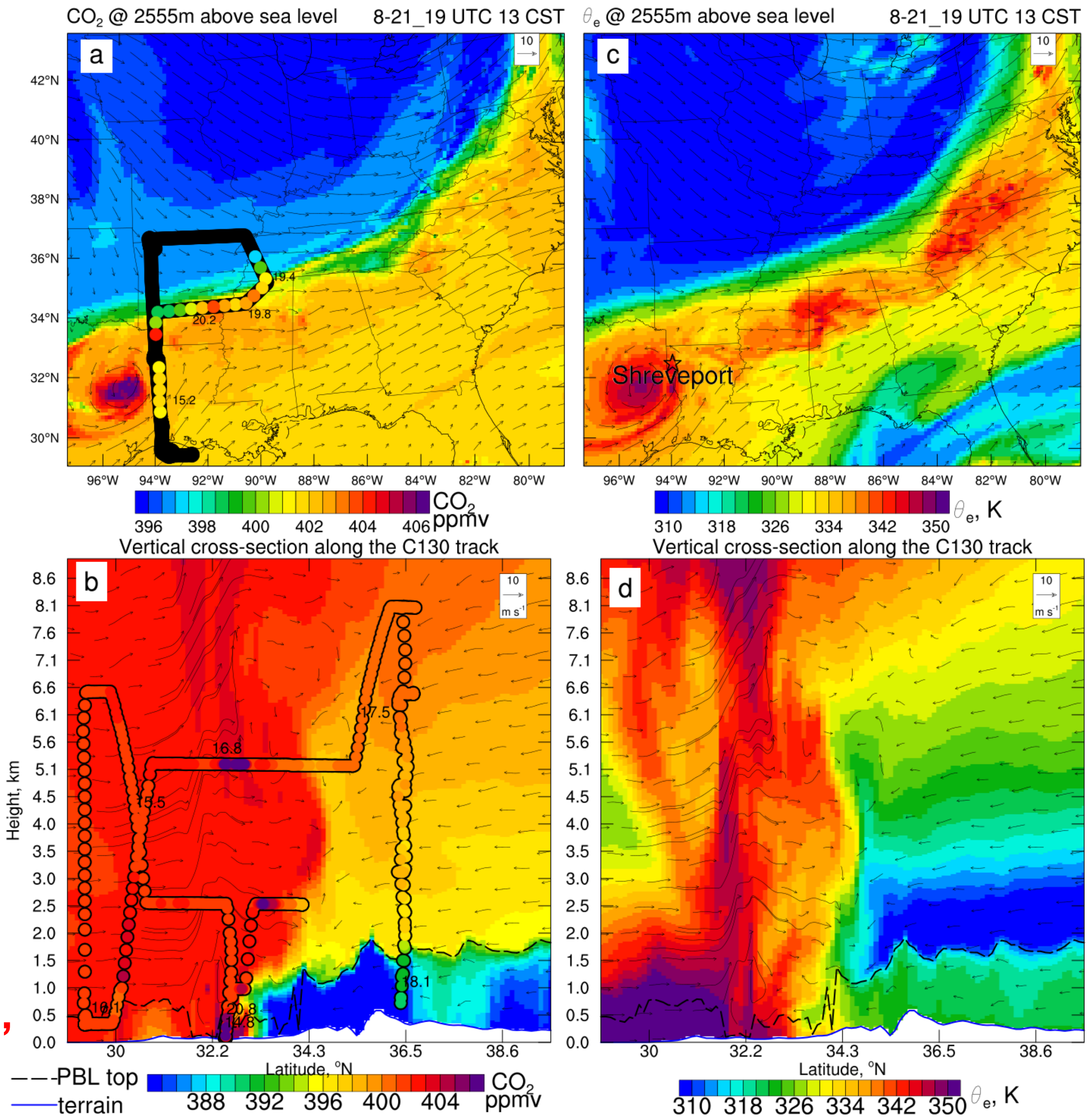
Capture the contrast across boundary layer top

Case study, Aug 5
OCO-2 underpass





Aug 21,2016

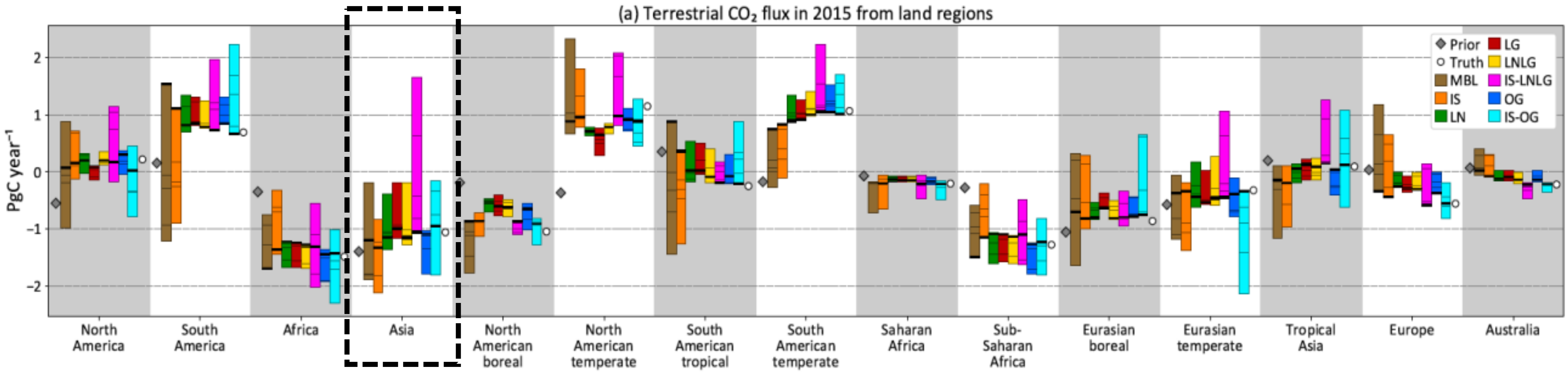


Capture the contrast across boundary layer top, and across cold front

Summary

1. Calibrated VPRM parameters from Hilton et al [2013] are implemented into WRF-VPRM
2. WRF-VPRM reasonably captures monthly variation of XCO_2 and episodic variations due to frontal passages
3. The downscaling also successfully captures the horizontal CO_2 gradients across fronts, as well as vertical CO_2 contrast across the boundary layer top.

Terrestrial CO_2 fluxes in different regions

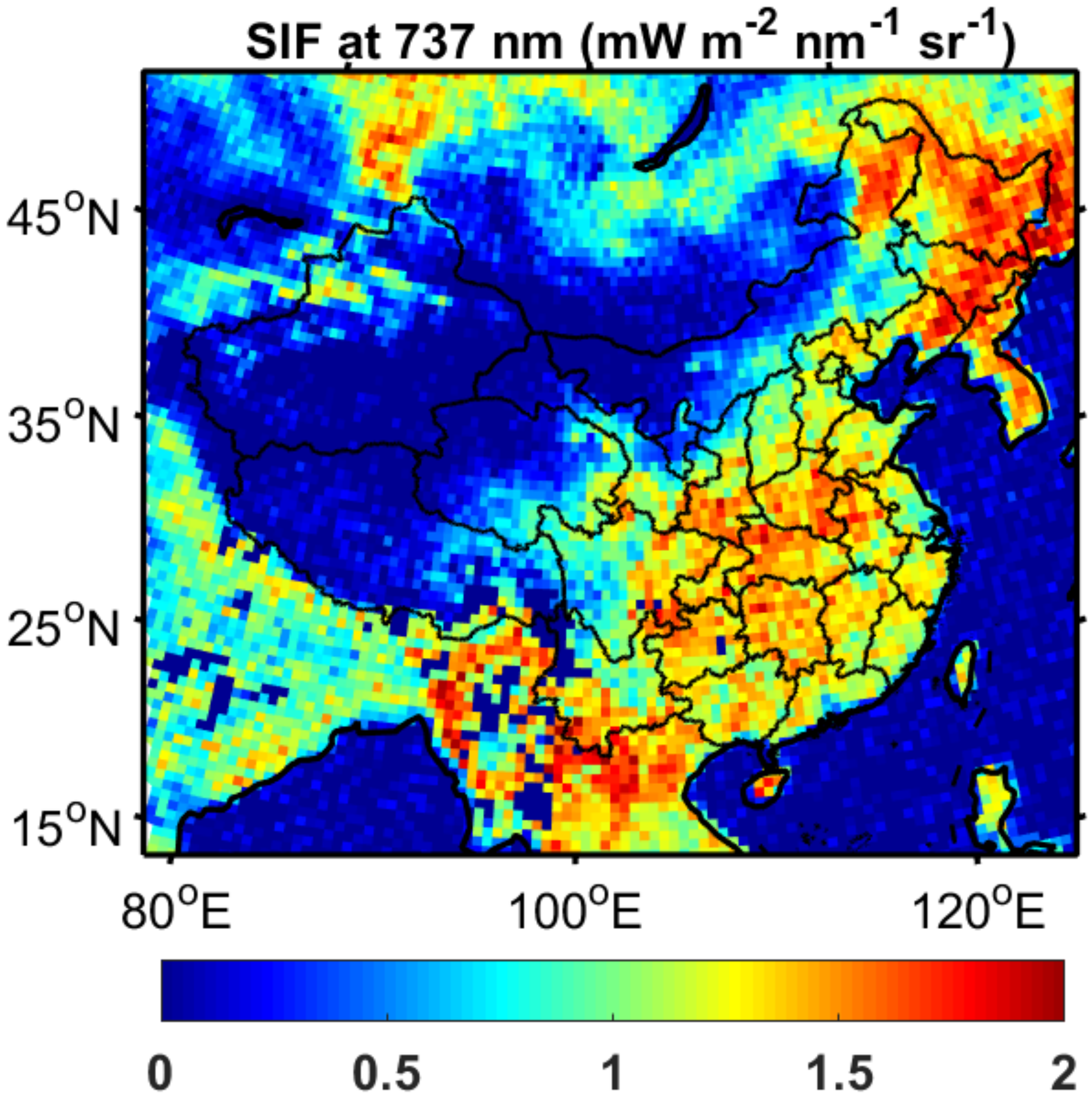


(Sourish Basu et al., 2018)

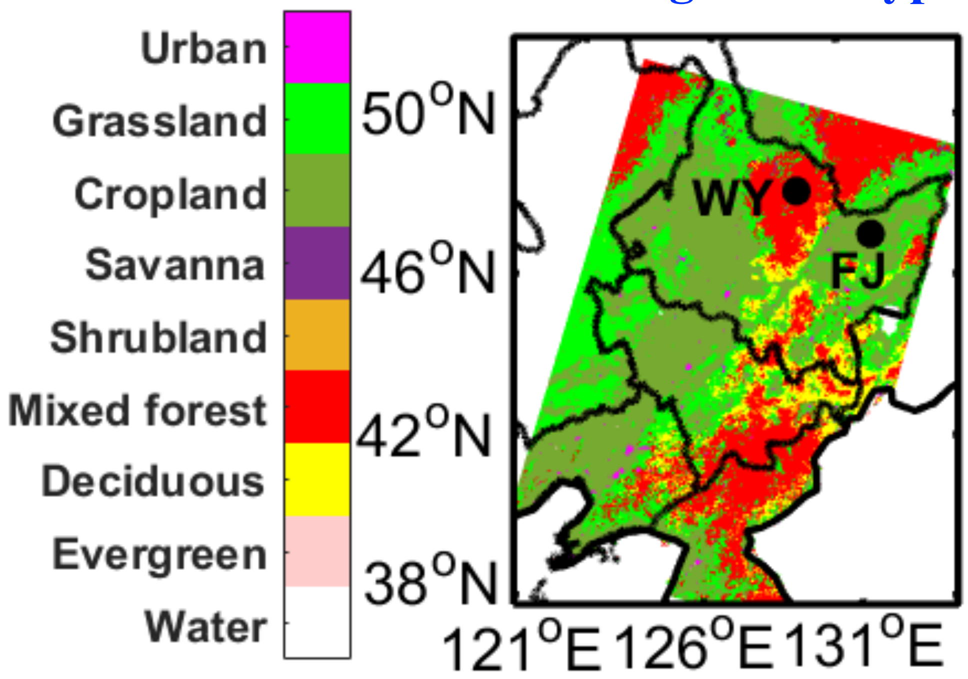
Uncertainties in each region are large too

Asia is CO_2 sink!!

Northeast China: a major CO_2 sink



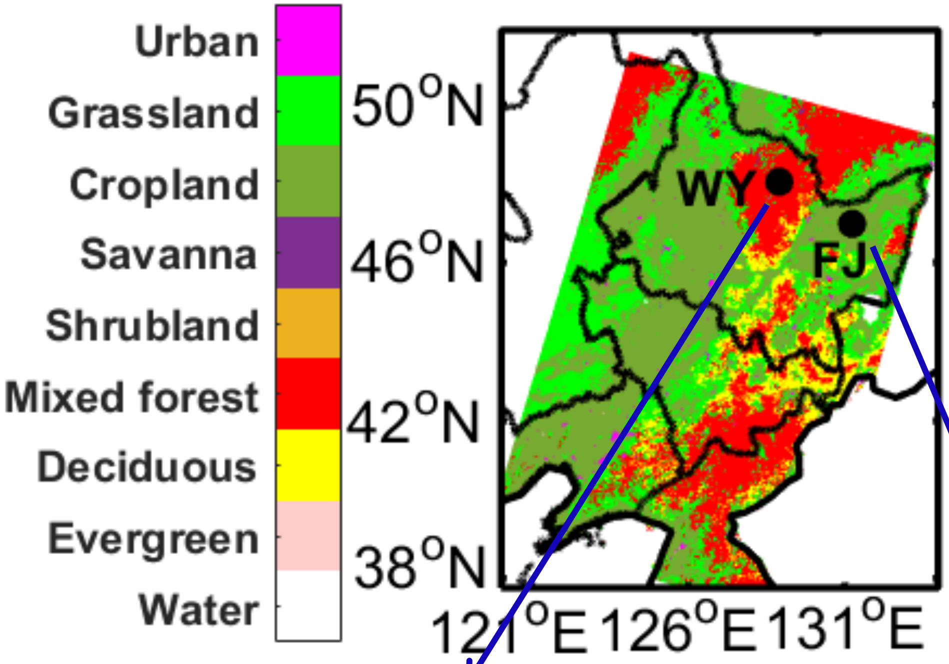
MODIS vegetation type



Mixed forest and cropland dominate in Northeast China
Crop area is still increasing!!

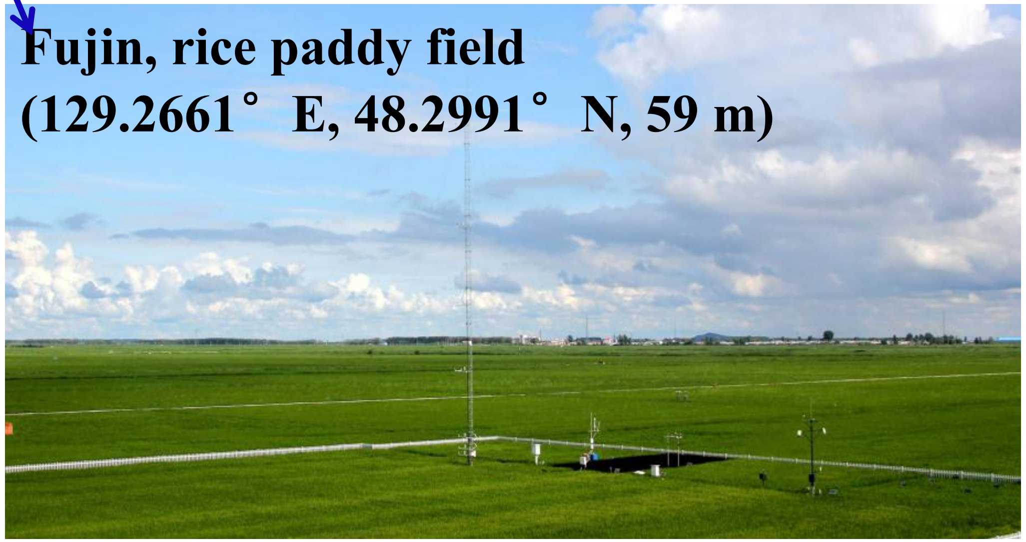
SIF: Sun-induced Fluorescence, proportional to photosynthesis

Long-term tower measurements, focusing on 2016

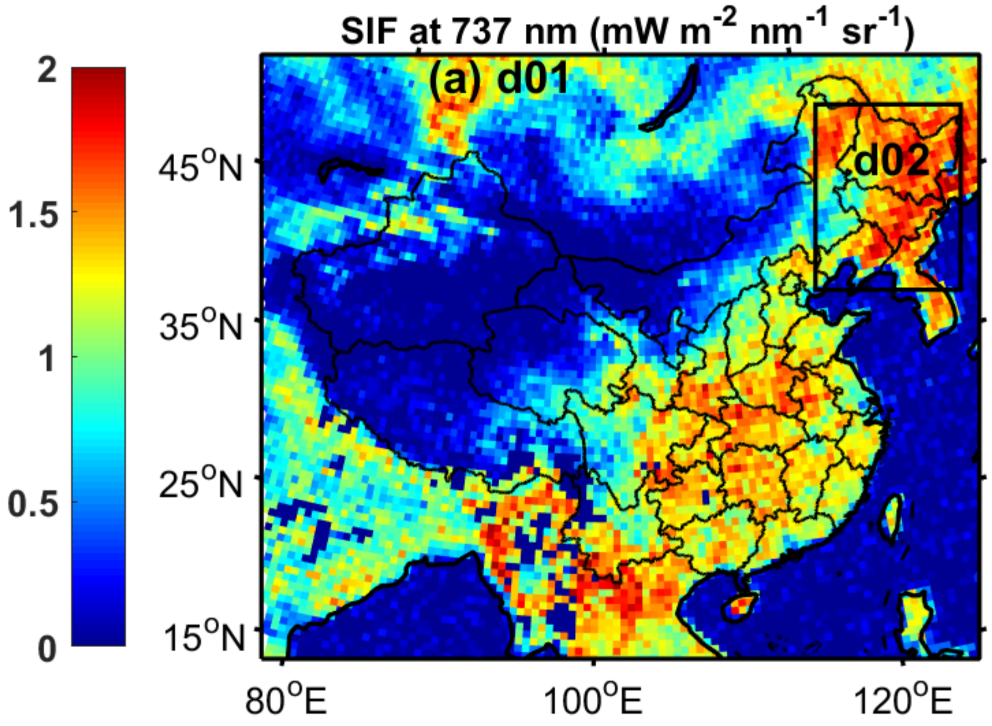


- **Observational parameters:**
  1) Hourly mean CO_2 fluxes and concentrations,
  2) wind speed and direction, air temperature
  3) PAR (only at Fujin)

- **Observational period:**
  Fujin: since 2012
  Wuying: since 2014



2016 downscaling using WRF-VPRM: a weather-biosphere-online-coupled model



$$NEE = (\alpha \times T + \beta) + GEE$$

$$GEE = -\lambda \times T_{scale} \times W_{scale} \times P_{scale} \times \frac{1}{1+\frac{PAR}{PAR_0}} \times FAPAR_{PAV} \times PAR$$

maximum light use efficiency

water stress scale

phenology scale

photosynthetically active radiation

Related to land surface water index (LSWI)

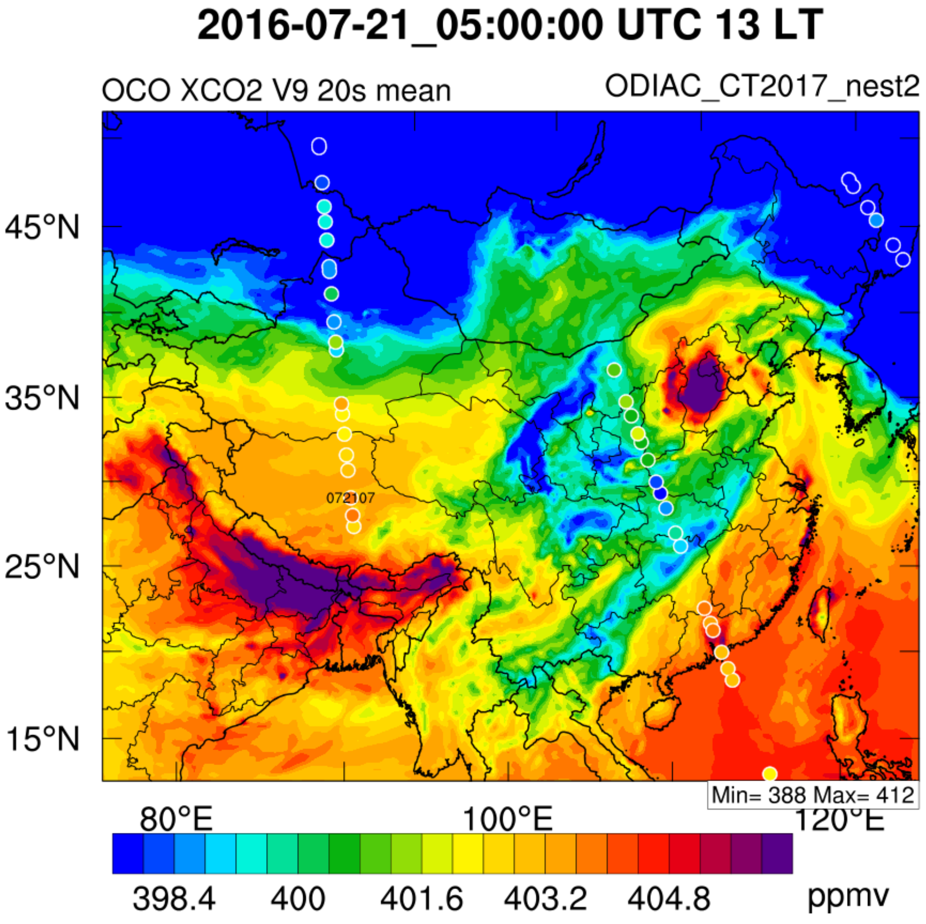
Roughly equal to enhanced vegetation index (EVI)

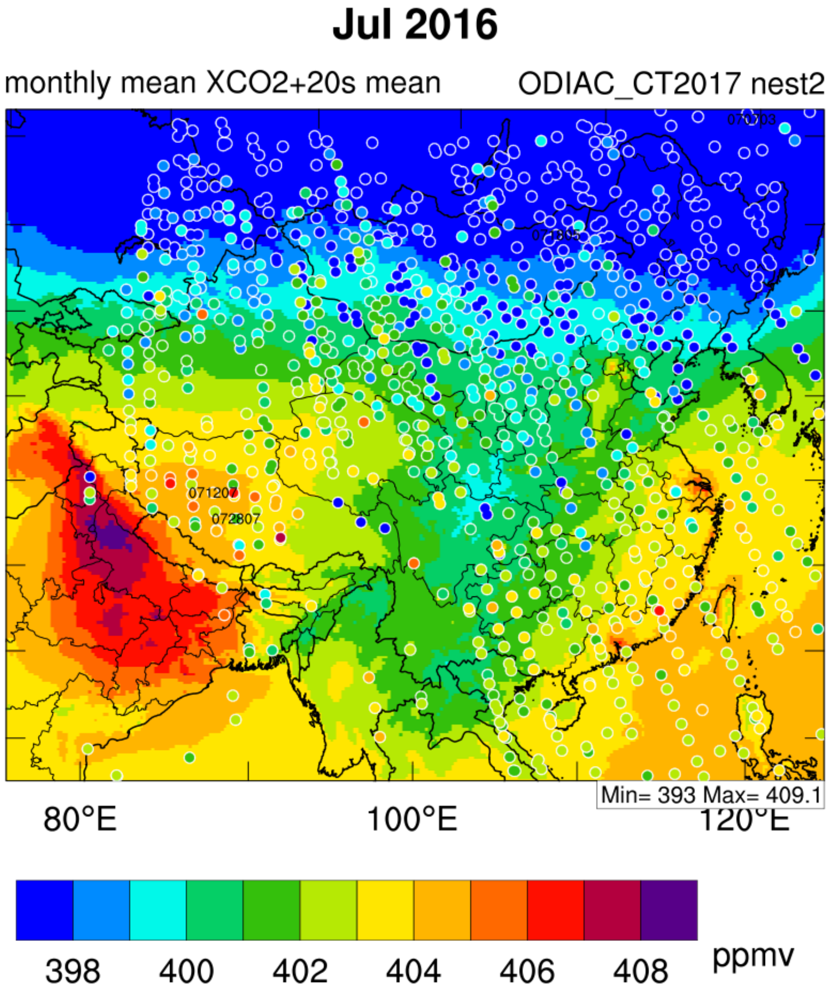
- **Resolution:** 20 km in d01; 4 km in d02
- **Meteorology initial/boundary conditions:** NECP/DOE R2
- **CO_2 initial/boundary conditions:** 3°×2° CarbanTracker 2017
- **Anthropogenic emissions of CO_2:** ODIAC

	Crops	Mixed forest	Evergreen forest	Deciduous forest	Shrub	Savanna	Grass
α	0.1300	0.2000	0.1247	0.0920	0.0634	0.2000	0.0515
β	0.5420	0.27248	0.2496	0.8430	0.2684	0.3376	-0.0986
λ	0.085	0.100	0.130	0.100	0.180	0.180	0.115
PAR_0	1074.9	419.50	745.306	514.13	590.7	600.0	717.1

Following Hu et al. (2019) based on Hilton et al. (2013)

OCO-2 retrieved XCO_2 (L2 Lite Version 9)



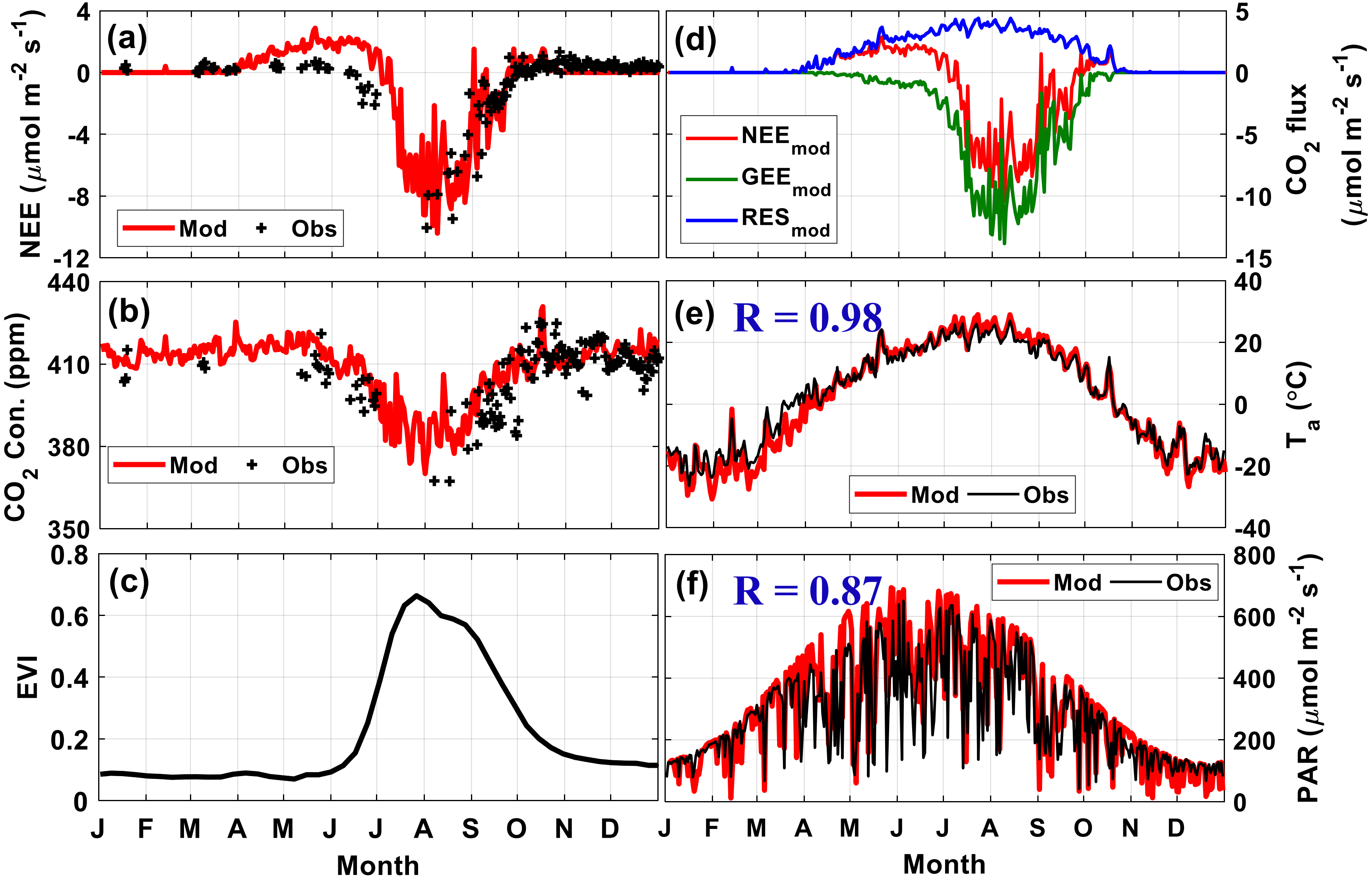


Advantage: spatiotemporal coverage

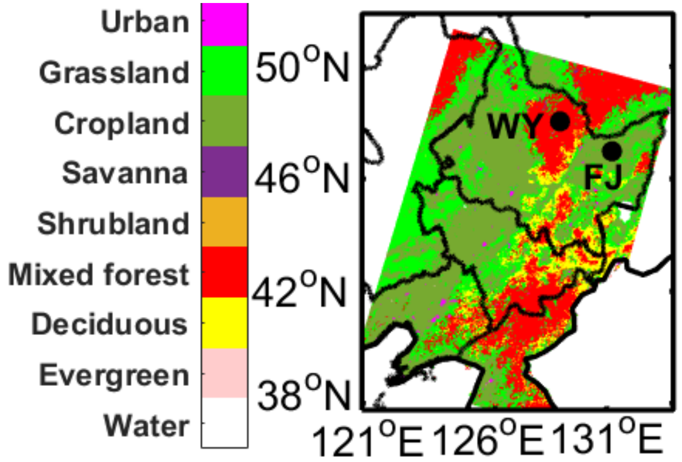
Disadvantage: interfere with cloud and haze pollution!!

Seasonal variations of CO_2 fluxes and concentrations

Fujin (cropland, rice paddy)

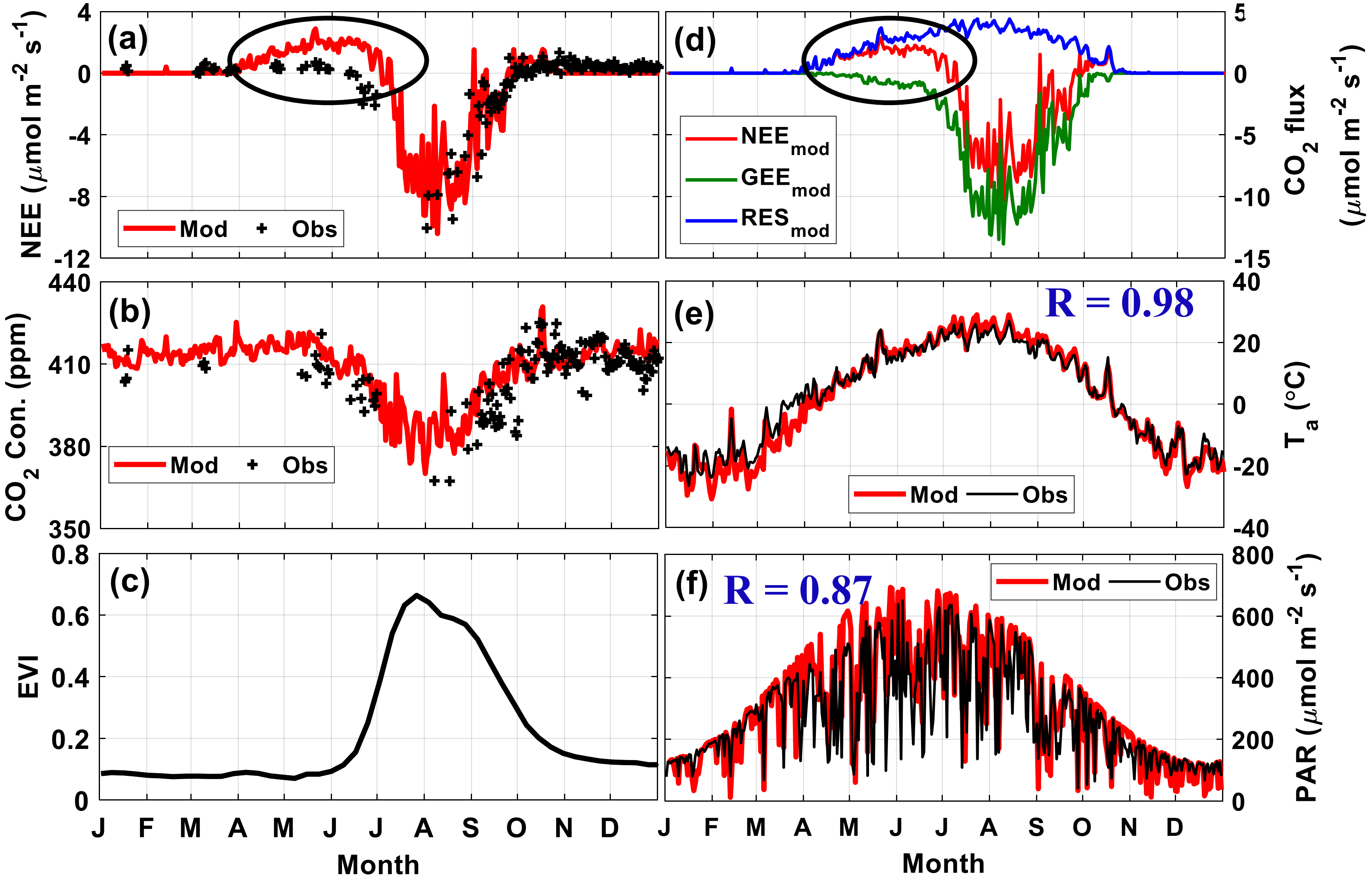


MODIS vegetation type



Bias of terrestrial respiration

Fujin (cropland, rice paddy)



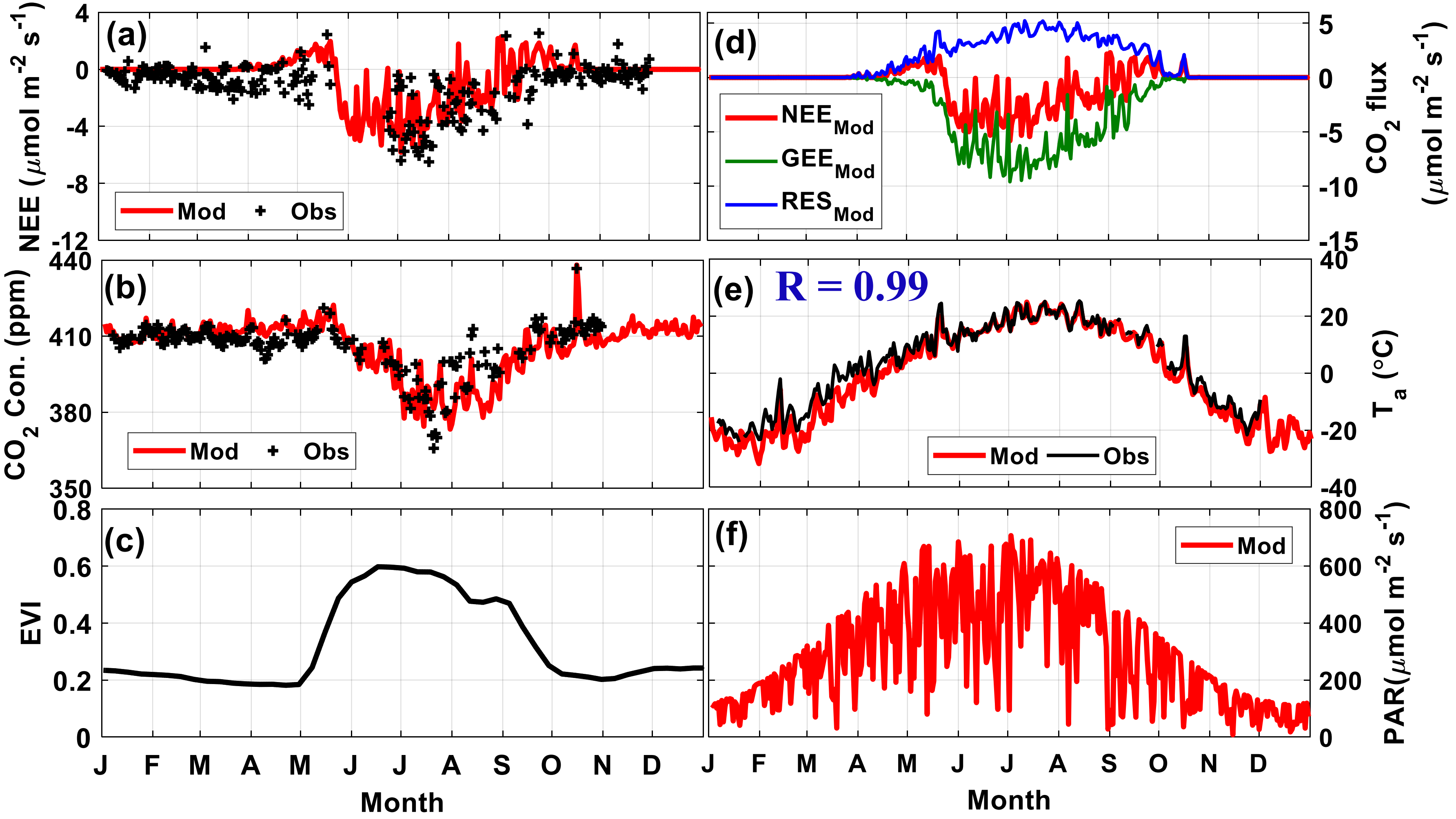
$$NEE = (\alpha \times T + \beta) + GEE$$

largely subjected to the EVI

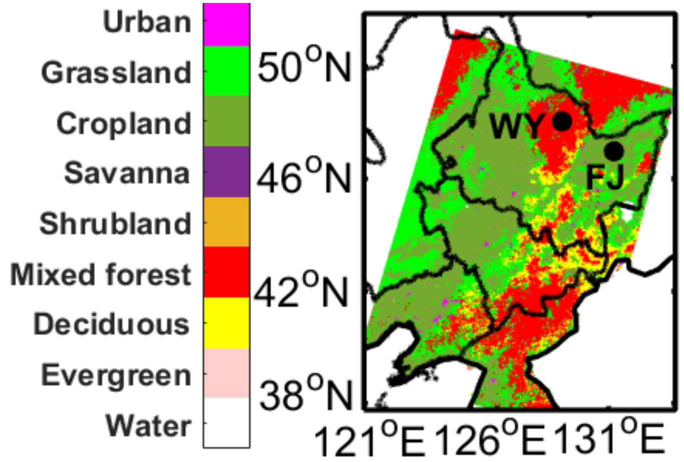
Ignores leaf mass, involves EVI?

Seasonal variation of CO_2 fluxes and concentrations

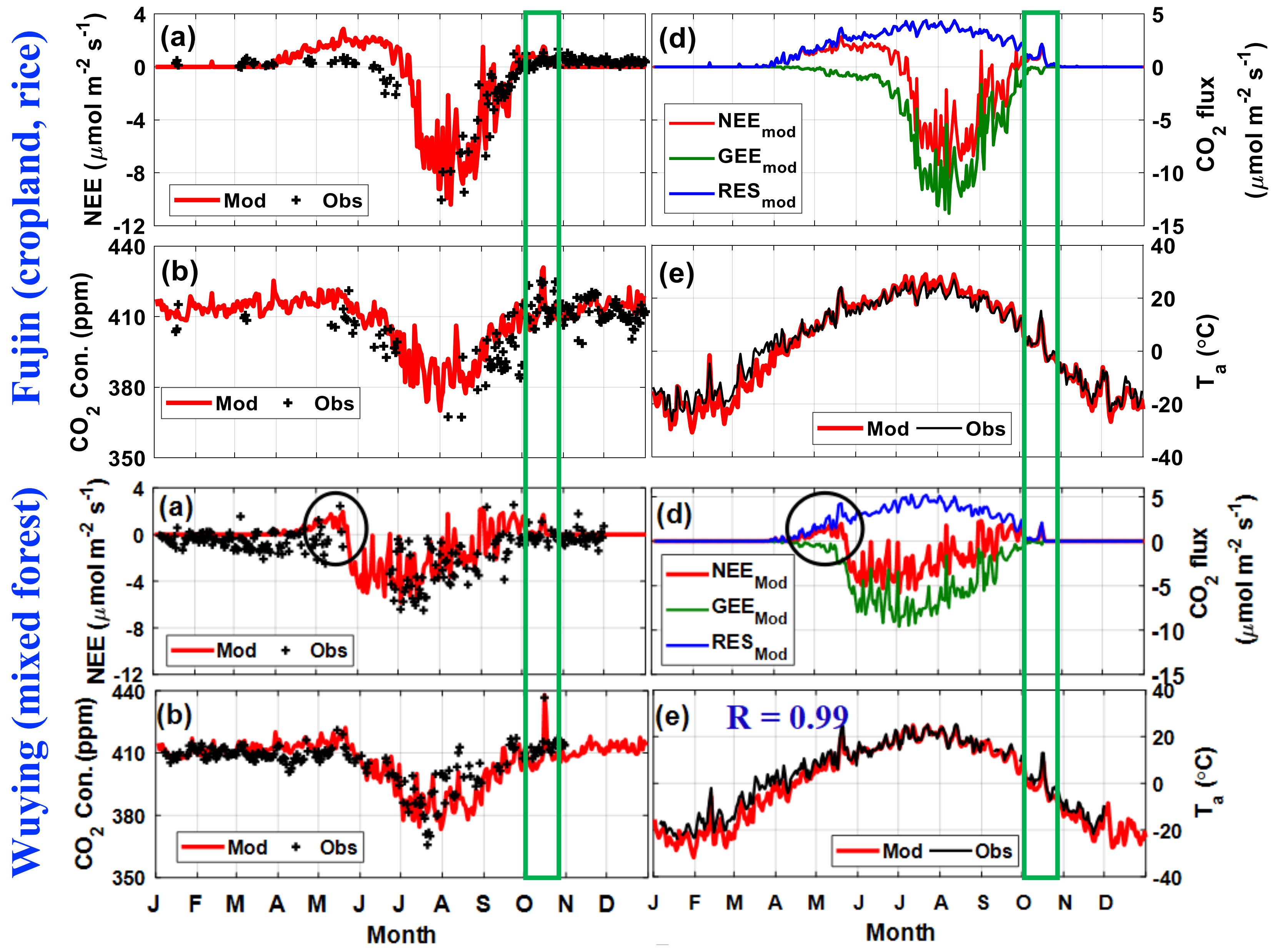
Wuying (mixed forest)

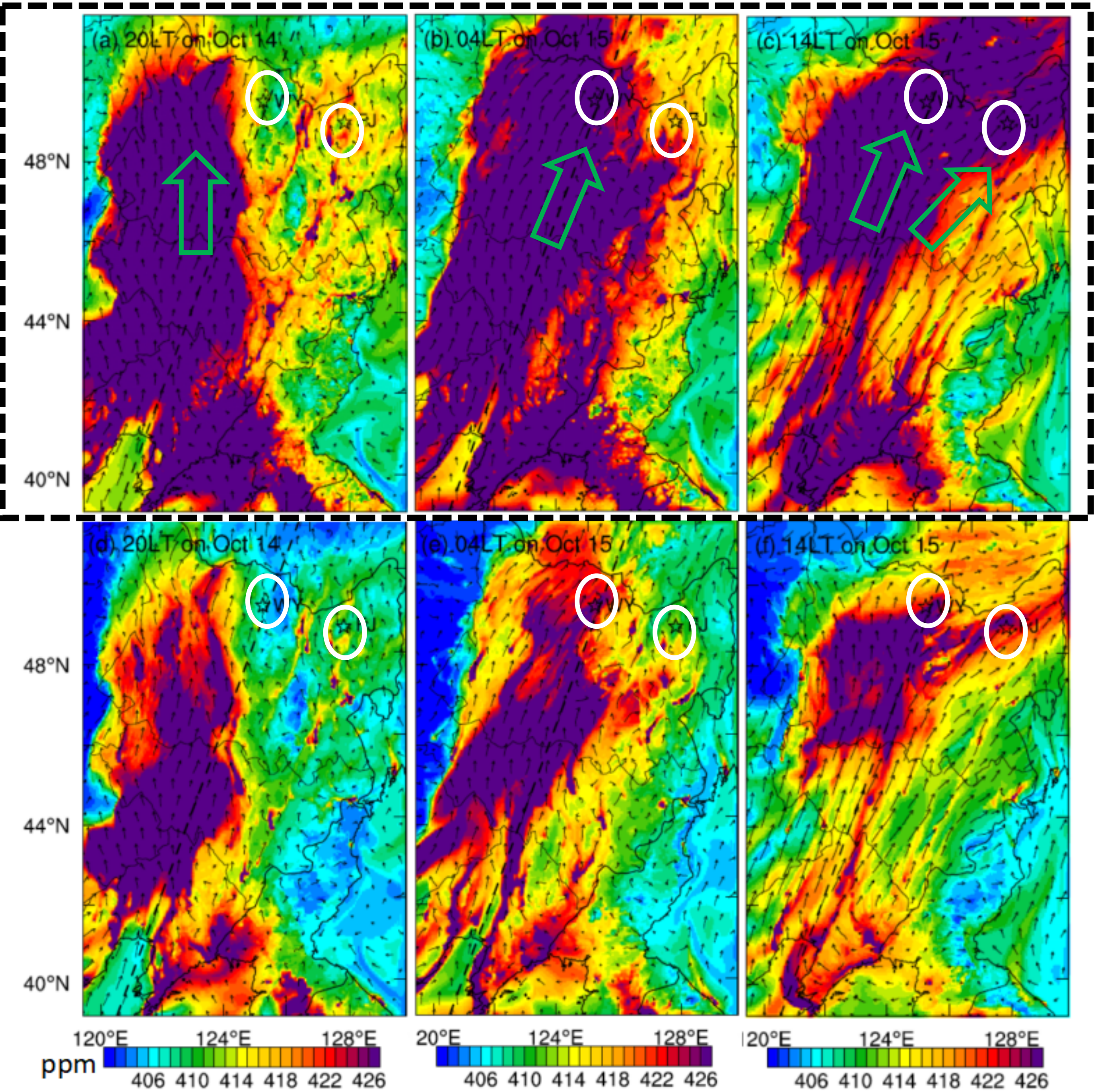


MODIS vegetation type



Episodic variation on October 15, 2016





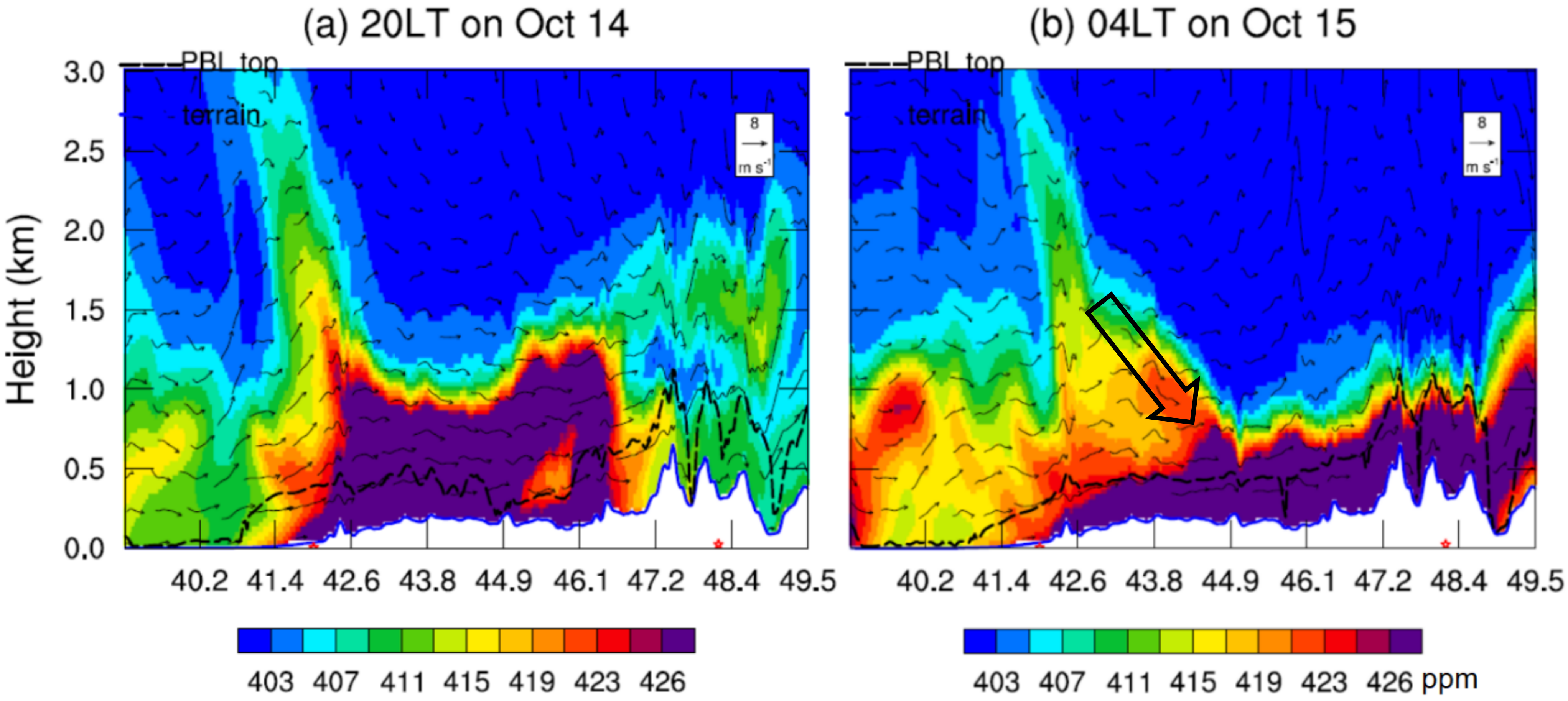
Regional transport on October 15

Anthropogenic emissions & biogenic contribution

Anthropogenic emissions only

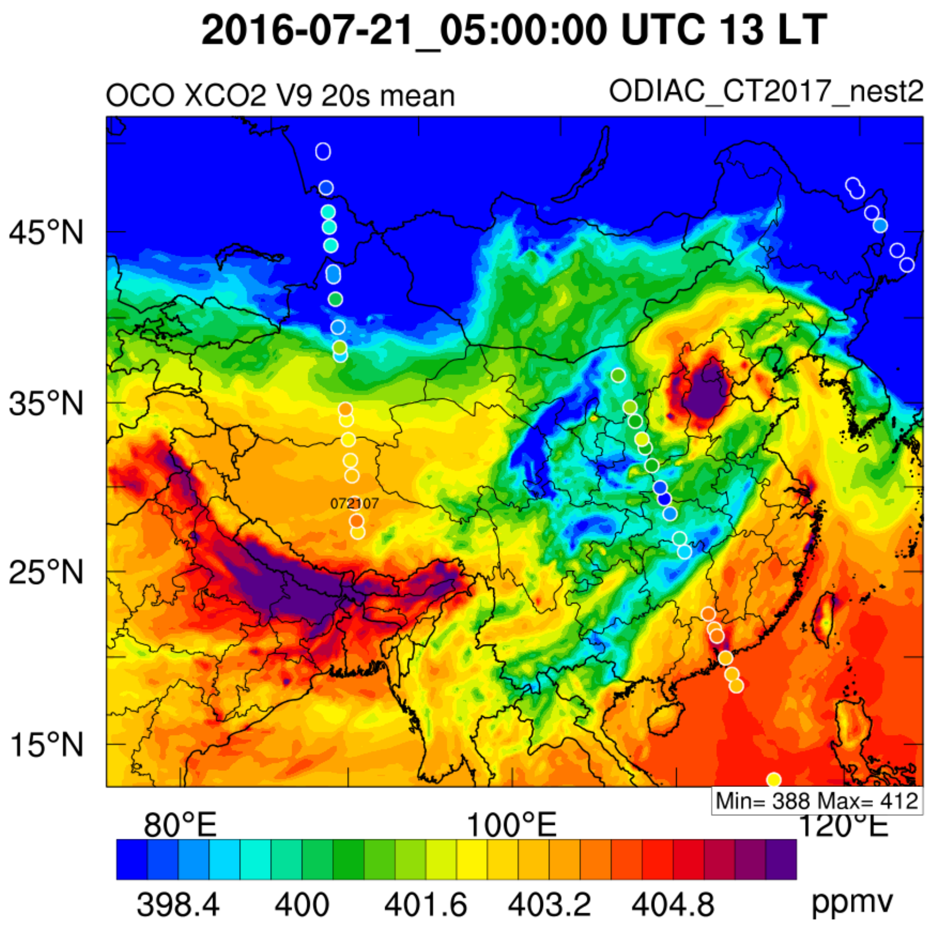
Anthropogenic contribution: 59.4 ± 5.9%
Biogenic contribution: 40.6 ± 5.9%

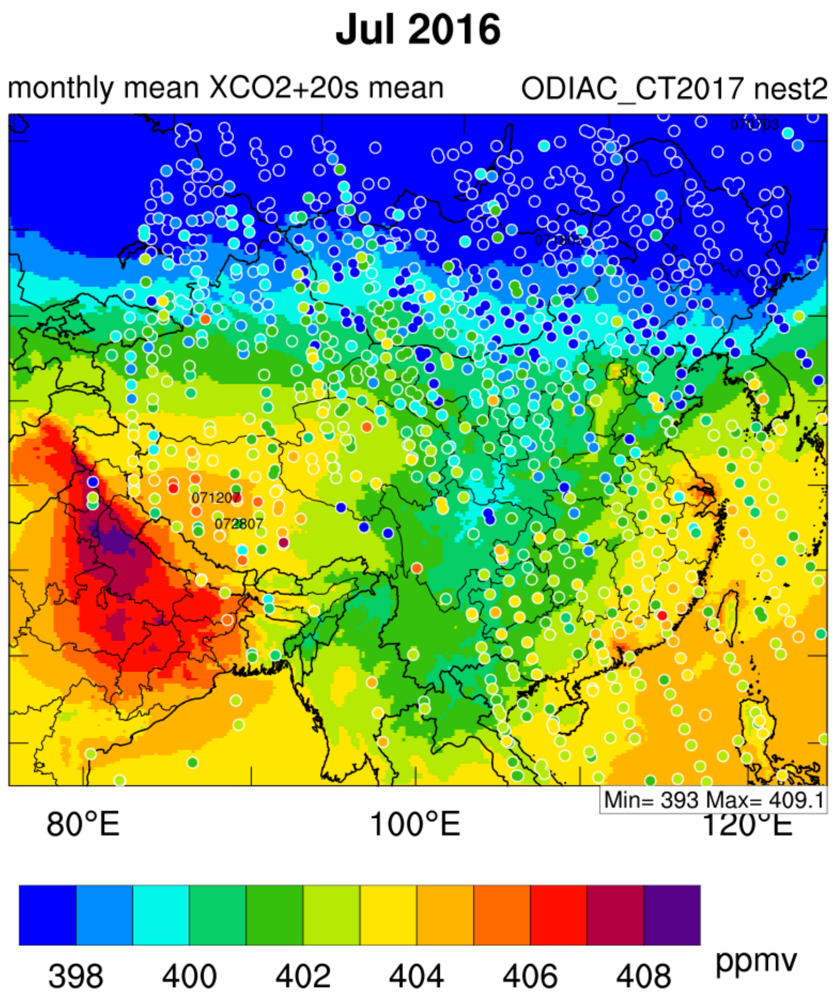
Vertical cross-section on October 15



Regional transport as well as subsidence?

OCO-2 retrieved XCO_2 (L2 Lite Version 9)

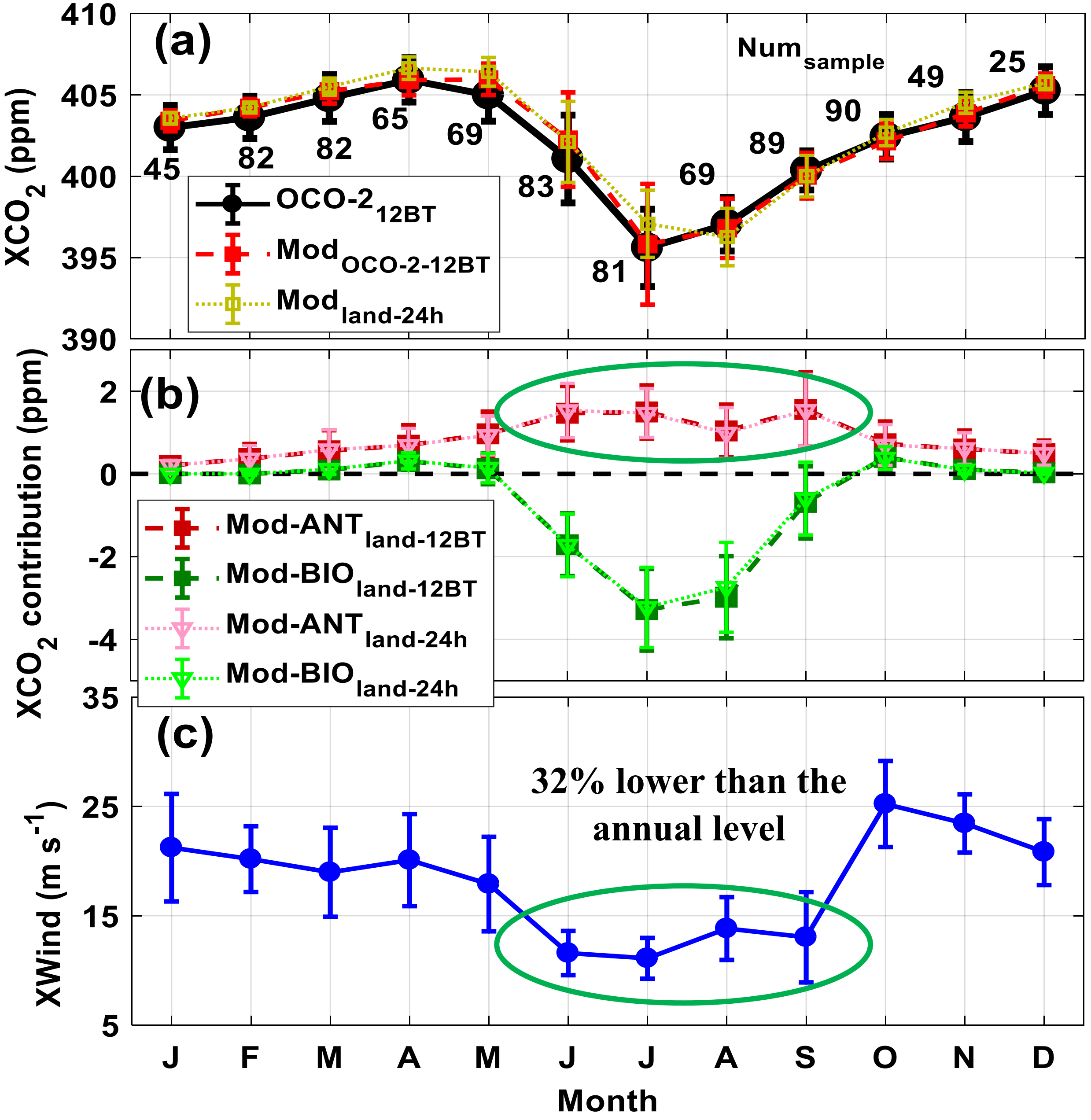




Advantage: spatiotemporal coverage

Disadvantage: interfere with cloud and haze pollution!!

Seasonal variation of XCO_2 over Northeast China



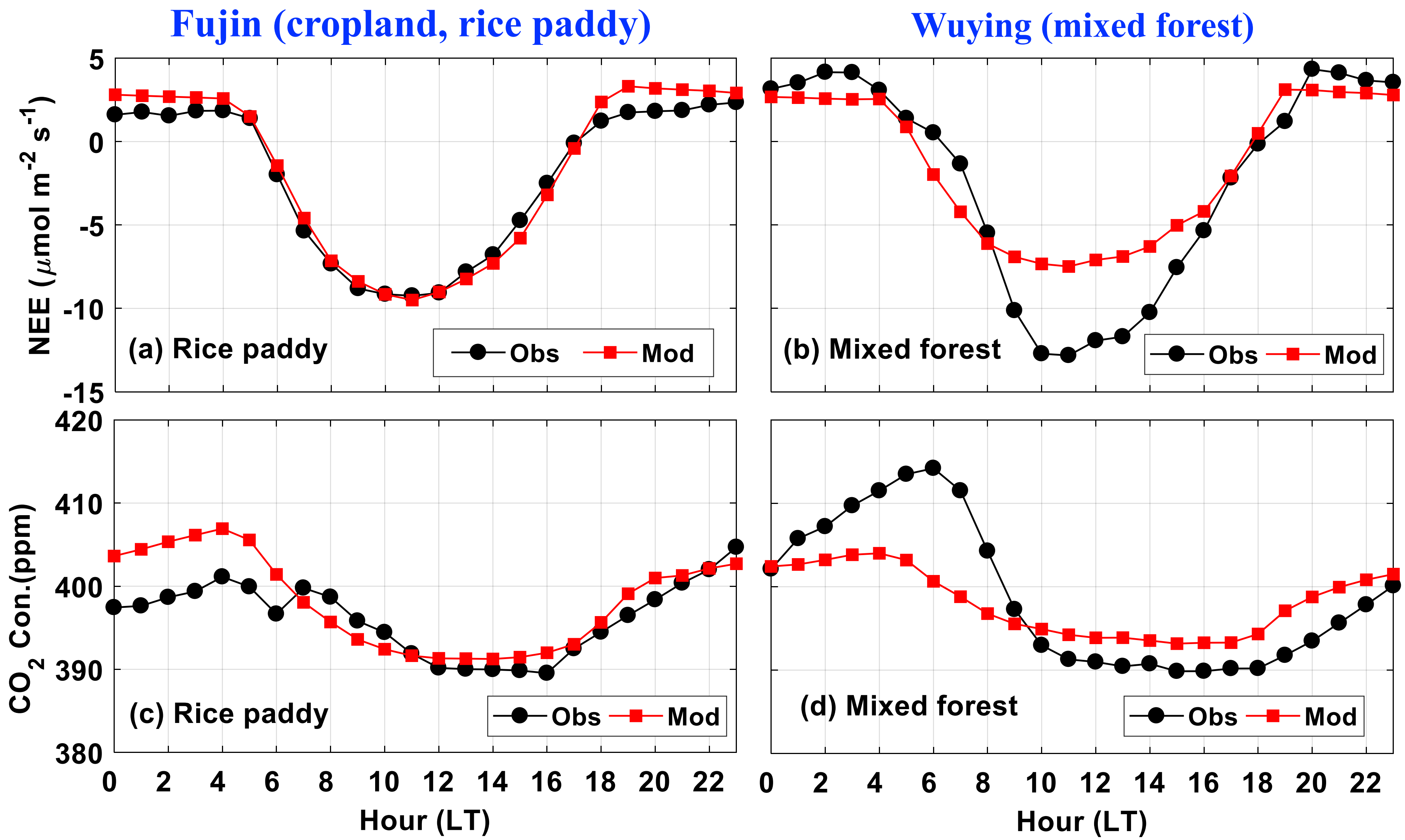
Seasonal variation range: 10 ppmv

Annual mean contribution:

- anthropogenic: 0.84 ppmv
- biogenic: -0.60 ppmv

Weak winds favors the large anthropogenic contribution of XCO_2 in summer

Mean diurnal variation of CO_2 fluxes and concentrations in growing season

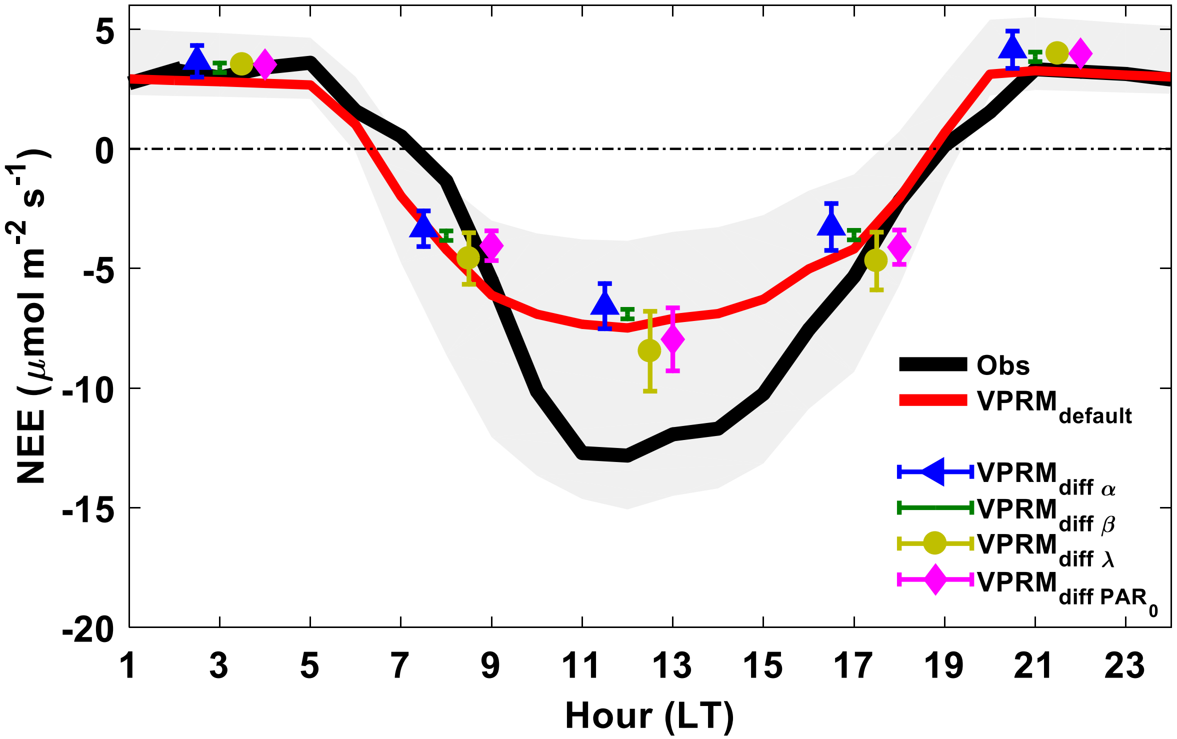


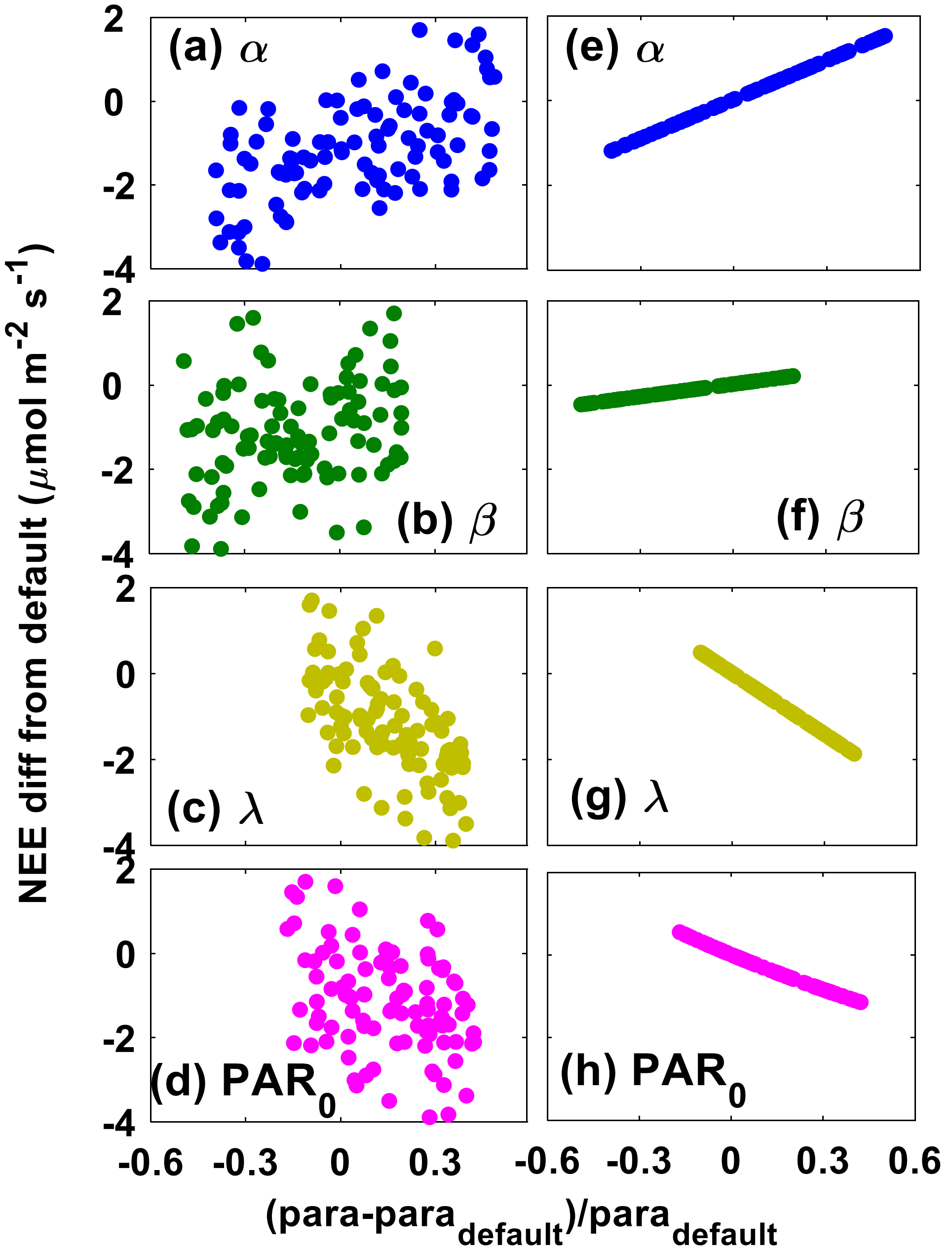
WRF-VPRM underestimates diurnal variation range over mixed forest

Ensemble offline VPRM simulations over mixed forest, predictability of CO_2 fluxes

Table 3 Range of VPRM parameters in five groups of ensemble simulations, with * representing relative variation to the default values

Ensemble Simulation	α	β	λ	PAR_0
ES1	[0.12, 0.30]	[0.50, 1.20]	[0.09, 0.14]	[350, 600]
	-40 ~ 50%*	-50 ~ 20%*	-10 ~ 40%*	-16.57 ~ 43.03%*
ES2	[0.12, 0.30]	1	0.1	419.5
ES3	0.2	[0.50, 1.20]	0.1	419.5
ES4	0.2	1	[0.09, 0.14]	419.5
ES5	0.2	1	0.1	[350, 600]





Conclusions and future work

- **Mixed forest is observed as a stronger CO_2 sink/source than rice paddy on average in 2016;**
- **Negative biogenic contribution offset about 70% of anthropogenic contribution of XCO_2 over Northeast China in 2016;**
- **The uncertainty of NEE simulation largely depends on four VPRM parameters, especially the maximum light use efficiency λ.**

Future: Update VPRM in WRF, including update the GEE equation and parameters.

$$GEE = (\lambda \times T_{scale} \times W_{scale} \times \cancel{P_{scale}}) \times FAPAR_{PAV} \times 1/(1 + PAR/PAR_0) \times PAR$$

$\parallel$

$\cancel{EVI}$

1.25*(EVI-0.1)

Also separate crop into C3/C4

CO_2 models

- Global models:
  - —Chemistry transport model TM3 (Heiman, 1996), TM5 (Krol et al., 2005)
  - —Laboratoire de Met´ eorologie Dynamique, LMDZ（Hauglustaine et al., 2004）
  - —ECHAM-4 (Max Planck Institute for Meteorology)
  - —CarbonTracker (only simulate CO_2 fluxes, not CO_2 concentrations)

- Regional models:
  - —NCAR episodic regional chemical transport mode, HANK（Hess et al., 2000）
  - —Danish Eulerian Hemispheric Model, DEHM (Christensen, 1997)
  - —REgional MOdel, REMO(Majewski, 1991)
  - —DEHM-LSM (land surface model), (Geel et al., 2004)
  - —RAMS-SiB2(Scott Denning et al., 2003)

Reference: https://www.atmos-chem-phys.net/7/3461/2007/acp-7-3461-2007.pdf