

Article

Supporting information for CO₂ flux over the contiguous United States in 2016 inverted by WRF-Chem/DART from OCO-2 XCO₂ retrievals

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Table S1. The information of inversion models in OCO-2 MIP version 7 [1].

Name	Transport model	Inversion methods	Spatial resolution	Prior land fluxes	Prior ocean fluxes	Prior fire emissions	Contact
TM54DVAR-NOAA_LN	TM5	4D-VAR	2°×3°	SiB-CASA	CT2015 Opt Clim	GFEDv4	Sourish Basu
Chevallier_LMDZ_Fix-Oceans_LN	LMDZ	4D-VAR	1.875°×3.75°	ORCHIDEE Clim	Landschutzer, <i>et al.</i> [2]	GFAS	Frédéric Chevallier
Deng_GEOSCHEM_LN	GEOS-Chem	4D-VAR	4°×5°	BEPS	Takahashi, <i>et al.</i> [3]	GFEDv4	Feng Deng
Baker_PCTM_Ldwo_LN	PCTM	4D-VAR	6.7°×6.7°	CASA-GFEDv3	Landschutzer, <i>et al.</i> [2] with a Southern Ocean sink added on	GFEDv3	David Baker
Baker_PCTM_Ldsh_LN	PCTM	4D-VAR	6.7°×6.7°	CASA-GFEDv3	Landschutzer, <i>et al.</i> [2]	GFEDv3	David Baker
SCHUH_LN	GEOS-Chem	Bayesian synthesis	1°×1°	SiB4/MERRA	CT2015 Opt Clim	None	Andrew Schuh
Baker_PCTM_NOBM_LN	PCTM	4D-VAR	6.7°×6.7°	CASA-GFEDv3	NOBM	GFEDv3	David Baker
Baker_PCTM_Taka_LN	PCTM	4D-VAR	6.7°×6.7°	CASA-GFEDv3	Takahashi, <i>et al.</i> [3]	GFEDv3	David Baker
UoE_LN	GEOS-Chem	EnKF	4°×5°	CASA	Takahashi, <i>et al.</i> [3]	GFEDv4	Liang Feng

Table S2. The information of CO₂ fluxes tower sites from AmeriFlux.

Code	Name	Vegetation type	Latitude (° N)	Longitude (° W)	DOI
US-ALQ	Allequash Creek Site	WET	46.0308	89.60673	10.17190/AMF/1480323
US-GLE	GLEES	ENF	41.36653	106.2399	10.17190/AMF/1246056
US-KFS	Kansas Field Station	GRA	39.0561	95.1907	10.17190/AMF/1246132
US-KLS	Kansas Land Institute	GRA	38.7745	97.5684	10.17190/AMF/1498745
US-Los	Lost Creek	WET	46.0827	89.9792	10.17190/AMF/1246071
US-MOz	Missouri Ozark Site	DBF	38.7441	92.2	10.17190/AMF/1246081
US-OWC	Old Woman Creek	WET	41.3795	82.5125	10.17190/AMF/1418679
US-PFa	Park Falls/WLEF	MF	45.9459	90.2723	10.17190/AMF/1246090
US-PHM	Plum Island High Marsh	WET	42.7423	70.8301	10.17190/AMF/1543377
US-Ro1	Rosemount-G21	CRO	44.7143	93.0898	10.17190/AMF/1246092
US-Ro2	Rosemount-C7	CRO	44.7288	93.0888	10.17190/AMF/1418683
US-Ro4	Rosemount Prairie	GRA	44.6781	93.0723	10.17190/AMF/1419507
US-Syv	Sylvania Wilderness Area	MF	46.242	89.3477	10.17190/AMF/1246106
US-Ton	Tonzi Ranch	WSA	38.4316	120.9660	10.17190/AMF/1245971
US-UMB	Univ. of Mich. Biological Station	DBF	45.559	84.7138	10.17190/AMF/1246107
US-UMd	UMBS Disturbance	DBF	45.5625	84.6975	10.17190/AMF/1246134
US-Var	Vaira Ranch- Ione	GRA	38.4133	120.9507	10.17190/AMF/1245984
US-Wcr	Willow Creek	DBF	45.8059	90.0799	10.17190/AMF/1246111

Table S3. The information of CO₂ fluxes tower sites from ONEFlux.

Code	Name	Vegetation type	Latitude (° N)	Longitude (° W)	DOI
US-Men	Lake Mendota, Center for Limnology Site	WAT	43.0773	89.4030	10.17190/AMF/1433375
US-UMB	Univ. of Mich. Biological Station	DBF	45.5598	84.7138	10.17190/AMF/1246107
US-Mpj	Mountainair Pinyon-Juniper Woodland	OSH	34.4384	106.2377	10.17190/AMF/1246123
US-Ho1	Howland Forest (main tower)	ENF	45.2041	68.7402	10.17190/AMF/1246061
US-Ses	Sevilleta shrubland	OSH	34.3349	106.7442	10.17190/AMF/1246125
US-Seg	Sevilleta grassland	GRA	34.3623	106.7019	10.17190/AMF/1246124
US-Bar	Bartlett Experimental Forest	DBF	44.0646	71.28808	10.17190/AMF/1246030
US-Pnp	Lake Mendota, Picnic Point Site	WAT	43.0896	89.4158	10.17190/AMF/1433376
US-Vcm	Valles Caldera Mixed Conifer	ENF	35.8884	106.5321	10.17190/AMF/1246121
US-Wjs	Willard Juniper Savannah	SAV	34.4255	105.8615	10.17190/AMF/1246120

Table S4. The information of ground-based CO₂ concentration observation sites.

Type	Sites	Latitude (° N)	Longitude (° W)	Altitude (m)	Sample height (m AGL)
TCCON	Park Falls	45.945	90.273	440	/
	Lamont	36.604	97.486	320	/
	Edwards	34.958	117.882	699	/
	Pasadena	34.202	118.175	390	/
Towers from Ob- sPack	LEF (Park Falls, Wisconsin)	45.9451	90.2732	472	396
	AMT (Argyle, Maine)	45.0345	68.6821	53	107
	OSI (Silverton, Oregon)	44.9986	122.695	351	269,
	HFM (Harvard Forest, Massachu- setts)	42.5378	72.1714	340	29
	WBI (West Branch, Iowa)	41.7248	91.3529	241.7	379
	MRC (Marcellus Pennsylvania)	41.4662	76.4188	591	61
	WGC (Walnut Grove, California)	38.265	121.4911	0	483
	SCT (Beech Island, South Carolina)	33.4057	81.8334	115.2	305
	GCI04 (Millerville, AL)	33.1759	85.8911	328	100
	WKT (Moody, Texas)	31.3149	97.3269	251	457

Table S5. Aircraft observations from ObsPack products used for evaluation.

Type	Code	Name	Latitude (° N)	Longitude (° W)
In-situ	TOM	Atmospheric Tomography Mission (ATom)	/	/
	ORC	ORCAS (O2/N2 Ratio and CO2 Airborne Southern Ocean Study)	/	/
	KORUS-AQ	Korea-United States Air Quality Study	/	/
	GSFC	NASA Goddard Space Flight Center Aircraft Campaign	/	/
	CON	CONTRAIL (Comprehensive Observation Network for TRace gases by AirLiner)	/	/
	ACT	Atmospheric Carbon and Transport - America	/	/
PFP	WBI	West Branch, Iowa	41.7248	91.3529
	THD	Trinidad Head, California	41.0541	124.151
	TGC	Offshore Corpus Christi, Texas	27.73	96.86
	SGP	Southern Great Plains, Oklahoma	36.607	97.489
	SCA	Offshore Charleston, South Carolina	32.77	79.55
	NHA	Offshore Portsmouth, New Hampshire Isles of Shoals	42.95	70.63
	LEF	Park Falls, Wisconsin	45.9451	90.2732
	INX	INFLUX (Indianapolis Flux Experiment)	39.5805	86.4207
	HIL	Homer, Illinois	40.07	87.91
	ESP	Estevan Point, British Columbia	49.383	126.5441
	DND	Dahlen, North Dakota	47.5	99.24
	CMA	Offshore Cape May, New Jersey	38.83	74.32
	CAR	Briggsdale, Colorado	40.6347	104.3269
	ACT	Atmospheric Carbon and Transport - America	/	/

Table S6. The monthly prior (PRIOR) and posterior (DA_FLUX) CO₂ flux of the DA_FLUX experiment, the monthly posterior fluxes from CT2017 and the models in OCO-2 MIP, over the contiguous United States in 2016.

Experiments	Monthly mean fluxes (Pg C month ⁻¹)												Annual (PgC y ⁻¹)
	1	2	3	4	5	6	7	8	9	10	11	12	
PRIOR	0.35	0.32	0.28	0.12	-0.05	-0.21	-0.20	-0.08	0.04	0.21	0.35	0.37	1.51
CT2017	0.30	0.28	0.26	0.09	-0.12	-0.37	-0.34	-0.03	0.12	0.27	0.32	0.39	1.19
DA_FLUX	0.33	0.27	0.19	0.05	-0.10	-0.17	-0.07	-0.02	0.07	0.16	0.19	0.19	1.08
TM54DVAR-NOAA_LN	0.30	0.31	0.29	0.06	-0.25	-0.44	-0.35	-0.04	0.16	0.21	0.30	0.27	0.82
Chevallier_LMDZ_Fix-Oceans_LN	0.27	0.29	0.23	-0.03	-0.29	-0.44	-0.31	0.00	0.14	0.18	0.27	0.23	0.53
Deng_GEOSCHEM_LN	0.28	0.25	0.25	0.11	-0.22	-0.43	-0.33	-0.02	0.12	0.24	0.25	0.27	0.76
Baker_PCTM_Ldwo_LN	0.23	0.33	0.23	0.02	-0.21	-0.36	-0.27	0.01	0.06	0.30	0.37	0.30	1.03
Baker_PCTM_Ldsh_LN	0.19	0.33	0.25	0.04	-0.2	-0.36	-0.32	0.01	0.01	0.29	0.35	0.34	0.94
SCHUH_LN	0.23	0.25	0.23	0.02	-0.31	-0.41	-0.27	-0.09	0.01	0.10	0.17	0.22	0.16
Baker_PCTM_NOBM_LN	0.26	0.34	0.23	0.01	-0.21	-0.39	-0.29	0.01	0.07	0.35	0.30	0.30	1.00
Baker_PCTM_Taka_LN	0.22	0.33	0.24	0.03	-0.21	-0.36	-0.28	0.02	0.06	0.29	0.37	0.30	1.03
UoE_LN	0.21	0.25	0.20	0.02	-0.15	-0.28	-0.22	-0.03	0.06	0.15	0.19	0.21	0.61

Table S7. Monthly mean of the prior (PRIOR) and posterior (DA_FLUX) CO₂ flux of the DA_FLUX experiment, the posterior flux of CT2017, and the CO₂ flux measurements.

Month	Dataset	Flux measurements (gC m ⁻² d ⁻¹)	Flux		
			PRIOR (gC m ⁻² d ⁻¹)	CT2017 (gC m ⁻² d ⁻¹)	DA_FLUX (gC m ⁻² d ⁻¹)
1	AmeriFlux	0.37	1.54	1.52	1.13
	ONEFlux	0.37	0.98	0.76	0.90
2	AmeriFlux	0.36	1.46	1.51	1.02
	ONEFlux	0.19	0.98	0.75	0.75
3	AmeriFlux	0.33	1.30	0.80	0.85
	ONEFlux	0.03	0.83	0.47	0.80
4	AmeriFlux	-0.16	0.83	0.74	0.61
	ONEFlux	-0.34	0.55	0.40	0.83
5	AmeriFlux	-0.65	-0.05	0.45	-0.10
	ONEFlux	-0.80	-0.31	0.13	0.07
6	AmeriFlux	-2.20	-1.17	-0.51	-0.68
	ONEFlux	-1.43	-0.84	-0.71	-0.50
7	AmeriFlux	-1.80	-1.07	-0.49	-0.21
	ONEFlux	-1.21	-0.66	-0.47	-0.34
8	AmeriFlux	-1.40	-0.50	-0.33	-0.17
	ONEFlux	-1.11	-0.33	-0.34	-0.36
9	AmeriFlux	-0.40	0.27	0.36	0.12
	ONEFlux	-1.03	-0.12	0.02	-0.13
10	AmeriFlux	0.65	1.38	1.42	0.84
	ONEFlux	-0.20	0.73	0.61	-0.31
11	AmeriFlux	0.76	1.77	1.93	1.08
	ONEFlux	-0.15	1.11	1.06	0.72
12	AmeriFlux	0.36	1.59	1.76	0.73
	ONEFlux	-0.79	1.01	1.09	0.26

Table S8. Mean and median CO₂ concentration values of the SIM, DA_FLUX experimental results, and observations from TCCON, tower, and aircraft.

Observation Type	Experiment	Mean (ppm)	Median (ppm)
TCCON	SIM	403.86	404.16
	DA_FLUX	403.67	403.95
	CT2017	403.39	403.55
	Observations	403.49	403.70
Tower	SIM	409.20	408.98
	DA_FLUX	407.74	408.08
	CT2017	408.49	409.66
	Observations	407.79	408.6
Aircraft	SIM	403.99	404.23
	DA_FLUX	404.14	404.33
	CT2017	404.08	404.41
	Observations	404.19	404.43

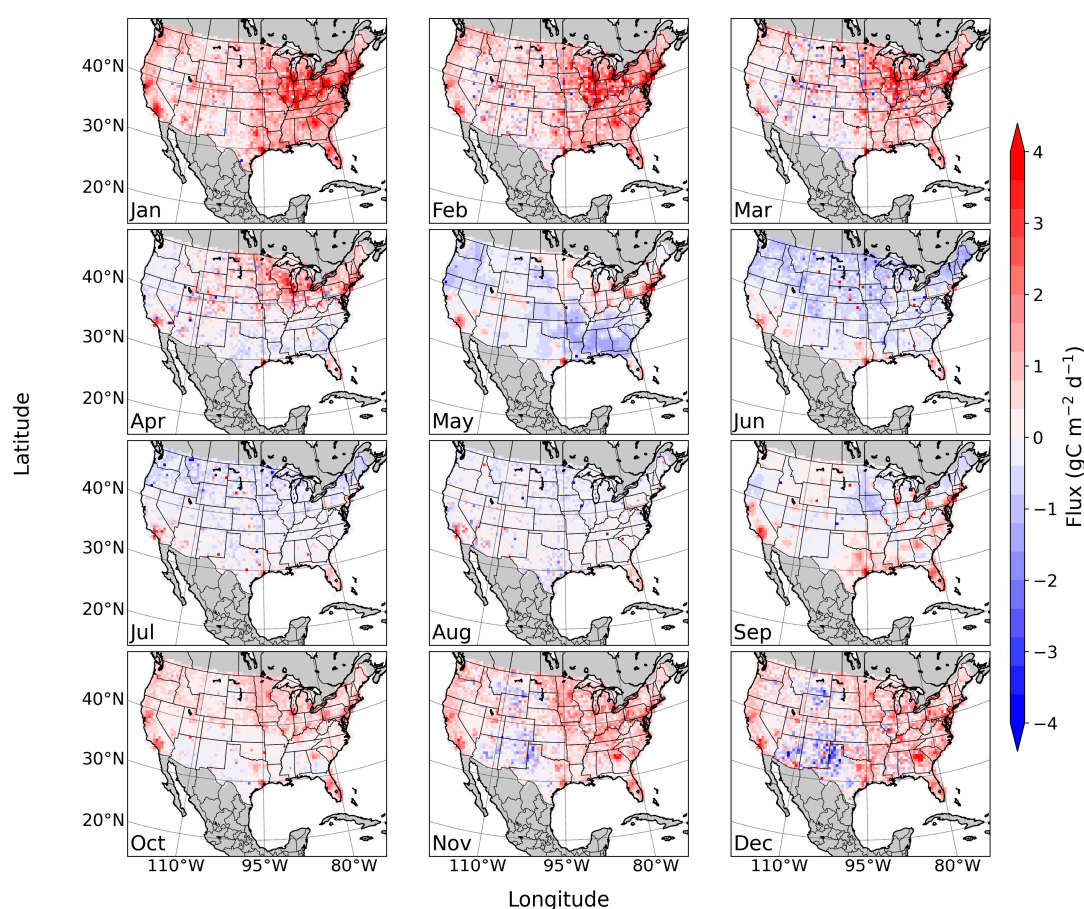


Figure S1. Spatial distributions of monthly mean posterior CO₂ fluxes estimated by the DA_FLUX experiment over the contiguous United States in 2016.

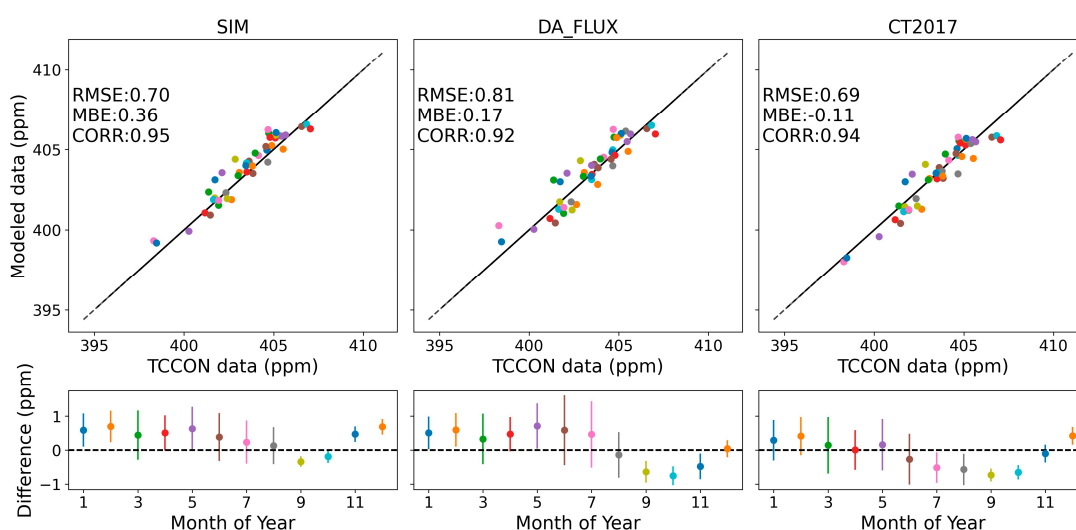


Figure S2. Comparison of the monthly mean TCCON observations and the modeled XCO₂ from the SIM, DA_FLUX experiment and CT2017. The top part shows scatter plots of the modeled XCO₂ against the TCCON observations. In the lower part, dot represents the mean bias error between the modeled XCO₂ and the TCCON observations, bar represents the standard deviation of the bias errors.

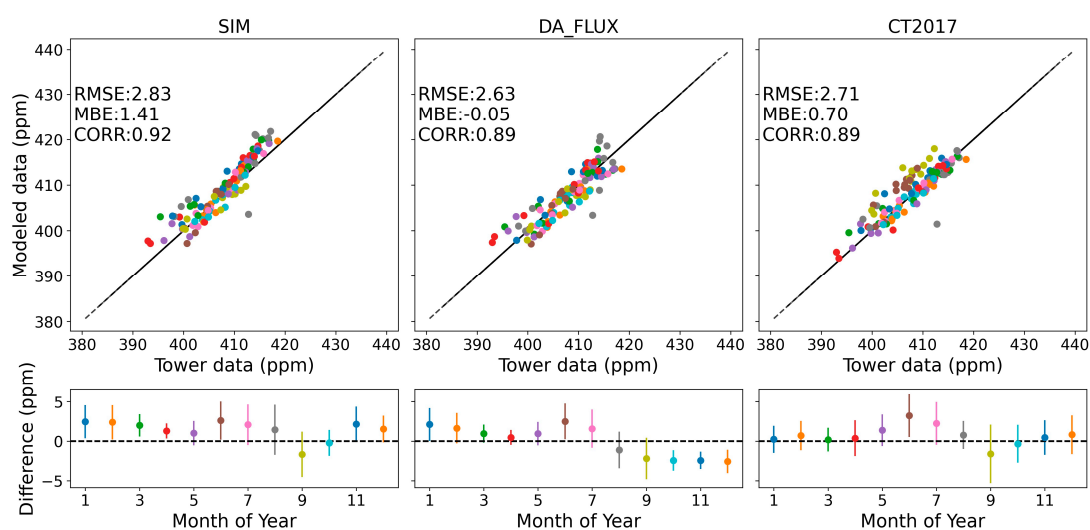


Figure S3. Comparison of the monthly mean tower observations and the modeled CO₂ concentrations from the SIM, DA_FLUX experiment and CT2017. The top part shows scatter plots of the modeled CO₂ concentrations against the tower observations. In the lower part, dot represents the mean bias error between the modeled CO₂ concentrations and the tower observations, bar represents the standard deviation of the bias errors.

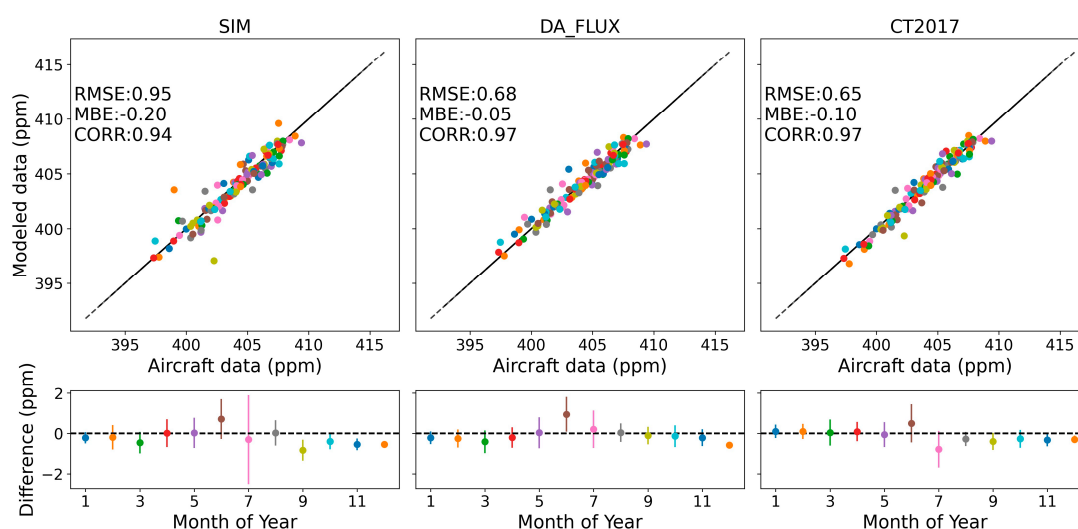


Figure S4. Comparison of the monthly mean aircraft observations and the modeled CO₂ concentrations from the SIM, DA_FLUX experiment and CT2017. The top part shows scatter plots of the modeled CO₂ concentrations against the aircraft observations. In the lower part, dot represents the mean bias error between the modeled CO₂ concentrations and the aircraft observations, bar represents the standard deviation of the bias errors.

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