Evaluation of Continental and Site Terrestrial Carbon Cycle Simulations with North American Flux Tower Observations

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North American Carbon Program Interim Synthesis Activity

The NACP Interim Synthesis Activity is a collaboration of terrestrial carbon modelers and analysts to collect a broad range of model output and eddy covariance flux tower observations. Regional terrestrial carbon model output is especially important to quantify the carbon flux balance across continental spatial domains. These models also help to attribute regions of carbon sources/sinks to the atmosphere and provide valuable information about carbon cycle dynamics.

In general, regional model performance is challenging to evaluate for lack of continental scale observations of carbon flux. Here, we use gap-filled carbon flux integrals derived from flux tower observations to evaluate regional modeled extracts of photosynthesis (GPP), total respiration (Re) and NEE (net ecosystem exchange) at annual and monthly temporal resolution.

Model-Data Comparison Setup:

-Flux Tower Sites: 36 North American sites consisting of 6 crop, 10 deciduous broadleaf (DBF), 4 boreal evergreen needleleaf (ENFB), 6 temperate evergreen needleleaf (ENFT), 3 grass, 7 miscellaneous (MISC). The MISC grouping consists of shrubland, tundra and wetland sites.

-Regional Models:

The 17 models use a variety of weather products (radiation, precipitation), photosynthetic formulations (enzyme-kinetic, light use efficiency) and soil decomposition formulations (nitrogen, no nitrogen). The asterisks denote 'cross-over' models that are run both across the continent and at individual sites. The site runs benefit from using site derived driver data whereas regional runs require regional driver data products.

Regional Models	Meteorology Driver	Phenology	Photosynthesis	Soil Decomp.
BEPS*	N/A	MODIS LAI	EK	1st order, w/N
CASA-GFED	IIASA, GISSTEMP, and	GIMMS NDVI	LUE	1st order
CASA-Trans	Leemans & Cramer	GIMMS NDVI	LUE	1st order
CLM-CASA	NCEP	Prognostic	EK	1st order
CLM-CN	NCEP	Prognostic	EK	1st order, w/N
Can-IBIS*	Canadian FSSD	Prognostic	EK	1st order
DLEM*	NARR & PRISM	Prognostic	EK	1st order, w/N
EC-MOD	Not Required	MODIS EVI, LAI	Statistical, DA	zero order
ISAM*	Mitchell et al. (2005)		LUE	1st order, w/N
LPJml*	CRU05	Prognostic	EK	1st order
MC1	PRISM	Prognostic	Statistical	1st order, w/N
MOD17	ERA-Interim reanalysis	MODIS LAI	LUE	zero order
NASA-CASA	NCEP	MODIS EVI	LUE	1st order, w/N
Orchidee*	CRU05/NCEP	Prognostic	EK	1st order, w/N
SIB3	NARR	MODIS LAI	EK	zero order
TEM6	CRU05/NCEP	Prognostic	EK	1st order, w/N
VEGAS2	CRU05/NCEP	Prognostic	LUE	1st order

Site level observations vs. regional model extracts: A caveat

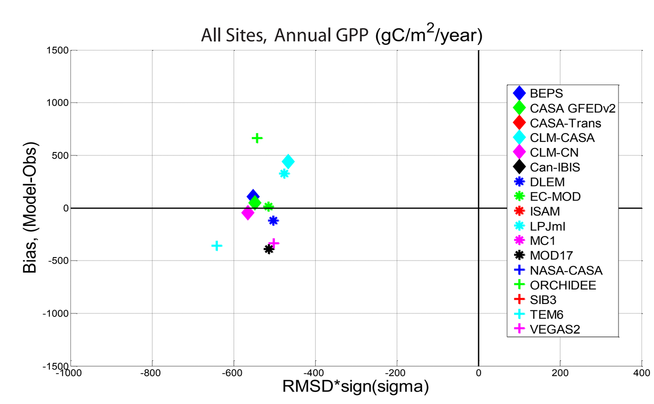
Although we assume the site level flux observations to be reality, there are several potential sources for model-data mismatch that are not inherently reflective of model performance:

- Representation Error: The site location may not represent the overall vegetation or climate characteristics within the 1X1 degree region that is modeled.
- Vegetation Mismatch: The regional vegetation map may be different than the actual site/region vegetation.
- Climate Mismatch: The regional climate product may differ significantly from the actual site/region climate.

-To a limited extent we can address these issues with site level model output, presumably immune to the above influences.

What regional models capture the observed magnitude of carbon fluxes?

Concurrent analyses within this NACP activity uncovered a wide range (5-25 PgC/year) for temperate North American GPP (Huntzinger et al, in prep).



The target diagram on the left includes all sites for each model. The models range from -50% to +50% of the observations, and are centered near a bias of zero. The Can-IBIS model had an unusually large bias and was not considered here. See table below for detailed description.

$gC/m^2/year$		BEPS	CASA_GFED	CASA-Trans	CLM-CASA	CLM-CN	Can-IBIS	DLEM	EC-MOD	ISAM	LPJml	MC1	MOD17	NASACASA	ORCHIDEE	SIB3	TEM6	VEGAS2
Annual NEE	bias	-20	136	157	95	116	132	145	-49	110	93	164	-75	141	11	156	32	134
	% bias	-15	88	114	71	87	85	94	-31	71	60	89	-56	96	7	101	29	87
Annual GPP	bias	109	47	NaN	440	-45	1127	-121	12	NaN	327	NaN	-391	NaN	666	NaN	-357	-337
	% bias	10	4	NaN	41	-4	103	-11	1	NaN	30	NaN	-36	NaN	60	NaN	-36	-31
Annual Re	bias	90	183	NaN	535	71	1259	25	-33	NaN	420	NaN	-467	NaN	677	NaN	-325	-203
	% bias	10	19	NaN	57	8	134	3	-3	NaN	45	NaN	-50	NaN	72	NaN	-36	-21

The best performing models in terms of gross fluxes are in green. Most models predict less carbon uptake than the flux tower observations (annual NEE).

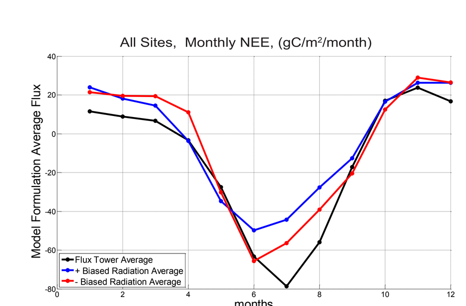
Do differences in the model run protocol influence the results?

We use the 'crossover' models to help diagnose the impact that the meteorological driver data, vegetation maps and spin-up procedures may have had upon the modeled fluxes.

		Annual Bias gC/m2/year					
		NEE		GPP		Re	
		Bias	Δ	Bias	Δ	Bias	Δ
ENFT	region	127	20	-103	194	14	259
	site	107		-297		-245	
DBF	region	95	-42	518	356	606	346
	site	137		162		260	
CROP	region	179	9	627	963	797	963
	site	170		-336		-166	
ENFB	region	-7	-11	508	203	500	193
	site	4		305		307	
GRASS	region	50	-24	382	438	428	413
	site	74		-56		15	
MISC	region	42	-19	724	399	767	421
	site	61		325		346	

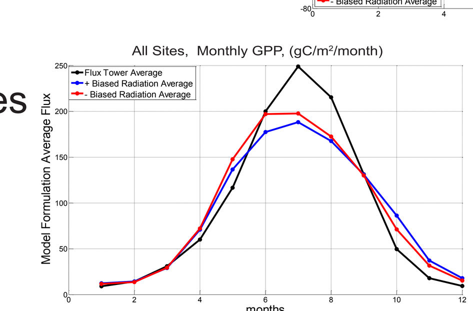
For all vegetation types the regional models are more positively biased than their site counterpart runs for the gross fluxes. The regional runs also predict more of a carbon sink (NEE) in general. Clearly, the differences in model protocol significantly influence the results.

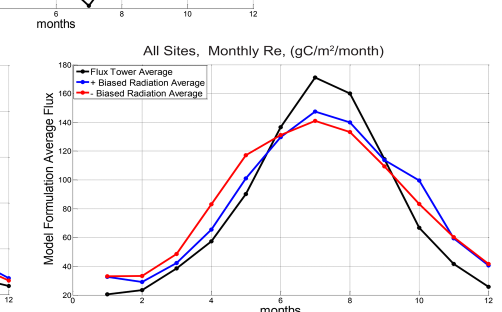
It was anticipated that the observed 15-40 % positive bias in the incoming SW regional radiation products (Ricciuto et al, in prep) led to the positive bias in GPP and Re fluxes.



Radiation Biases	
positive	negative
CLM-CASA	Orchidee
CLM-CN	TEM6
DLEM	Vegas2
MOD17	
NASA-CASA	
SIB3	

Surprisingly, there are no significant differences between models using known biased radiation products.

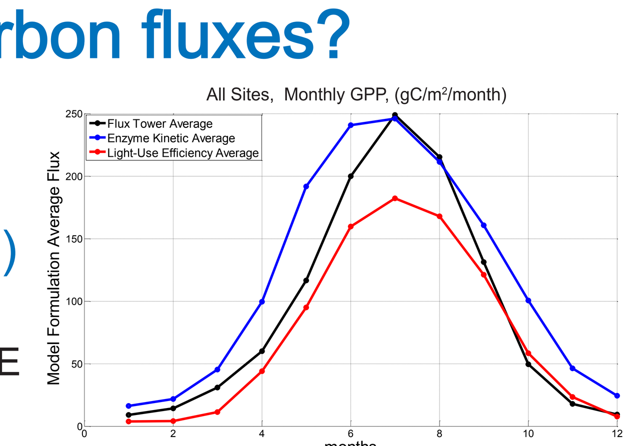




Does the model formulation influence the carbon fluxes?

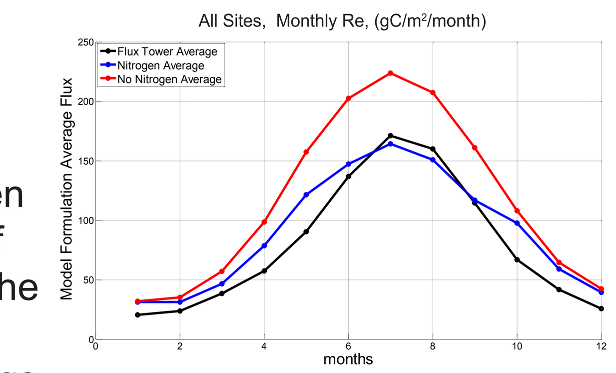
Phenology Formulation: Enzyme Kinetic (EK) vs Light Use Efficiency (LUE)

-EK models show equal and opposite bias as compared to LUE models. This is consistent with Huntzinger et al. (in prep).

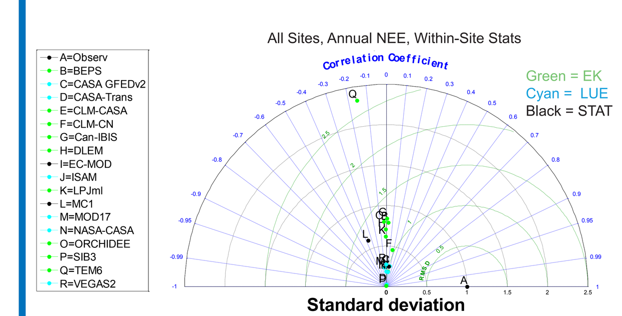


Soil Carbon Formulation: 1st Order with Nitrogen 1st Order w/out Nitrogen

-The models formulated with nitrogen are more limited in the magnitude of respiration. This is consistent with the idea that respiration is limited by nitrogen content, and with the findings of Huntzinger et al. (in prep).



Do the regional models capture inter-annual variability in NEE?



A Pearson correlation coefficient that surrounds zero for all models indicates little to no skill at predicting the year to year variability in NEE. Again, the crossover models can help determine whether this finding is an artifact of the model structure or model protocol (below).

The annual correlation is much improved for the gross fluxes and modestly improved for NEE. This suggests the poor correlation values for the regional models is only in part due to the model structure.

		Within-Site Annual Correlation (R-value) Mean Modeled Values											
		NEE				GPP				Re			
		Min	Max	Mean	Δ	Min	Max	Mean	Δ	Min	Max	Mean	Δ
ENFT	region	-0.28	0.36	0.11	-0.13	-0.48	0.28	-0.01	-0.33	-0.69	0.10	-0.25	-0.58
	site	-0.04	0.50	0.24		0.04	0.58	0.32		0.14	0.80	0.32	
DBF	region	-0.19	0.16	0.04	-0.16	-0.06	0.34	0.21	-0.33	0.18	0.25	0.21	-0.13
	site	-0.27	0.73	0.20		0.35	0.87	0.54		-0.07	0.56	0.34	
CROP	region	-0.73	0.25	-0.13	-0.85	-0.77	0.04	-0.32	-0.63	-0.63	0.17	-0.13	-0.45
	site	0.51	0.96	0.71		-0.32	0.99	0.31		-0.67	0.94	0.32	
ENFB	region	-0.11	0.52	0.18	0.04	0.45	0.81	0.56	-0.10	0.24	0.69	0.49	0.03
	site	-0.77	0.62	0.14		0.47	0.92	0.66		0.33	0.68	0.46	
GRASS	region	-0.33	0.74	0.14	-0.47	0.07	0.87	0.43	-0.31	-0.10	0.75	0.33	-0.19
	site	0.37	0.90	0.61		0.50	0.94	0.74		-0.15	0.89	0.53	
MISC	region	-0.23	0.45	0.22	0.24	-0.30	0.45	0.23	-0.29	-0.44	0.46	0.21	-0.19
	site	-0.99	0.27	-0.02		0.24	0.91	0.52		0.12	0.86	0.40	

Additional Findings:

-The within-site standard deviation for monthly integrals (all fluxes) is greater for the regional models as compared to the site models, whereas the annual integrals are about the same.

-The regional models are better able to capture across-site flux variability as compared to within-site variability by measure of correlation coefficient.

-Site level models outperform regional models in almost all statistical criteria. The unusually large positive bias for Can-IBIS reinforces this result.

- LUE models outperform EK models and nitrogen inclusive models outperform non-nitrogen models overall.

- The top performing regional models overall that did not use data assimilation are CASA-GFED(V2) and Vegas2.

Conclusions:

-The regional model average provides the best estimate for continental GPP. Individual model estimates are subject to large deviations from the observations.

-Regional estimates of inter-annual variability should be interpreted with great caution.

-Regionally derived driver data impairs the ability to evaluate regional model performance based on structural considerations alone.

-It is unclear what differences in model protocol contribute to the weakening of regional model skill.

-The choice of driver data and choice of model are likely equally as influential upon predicted fluxes.

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