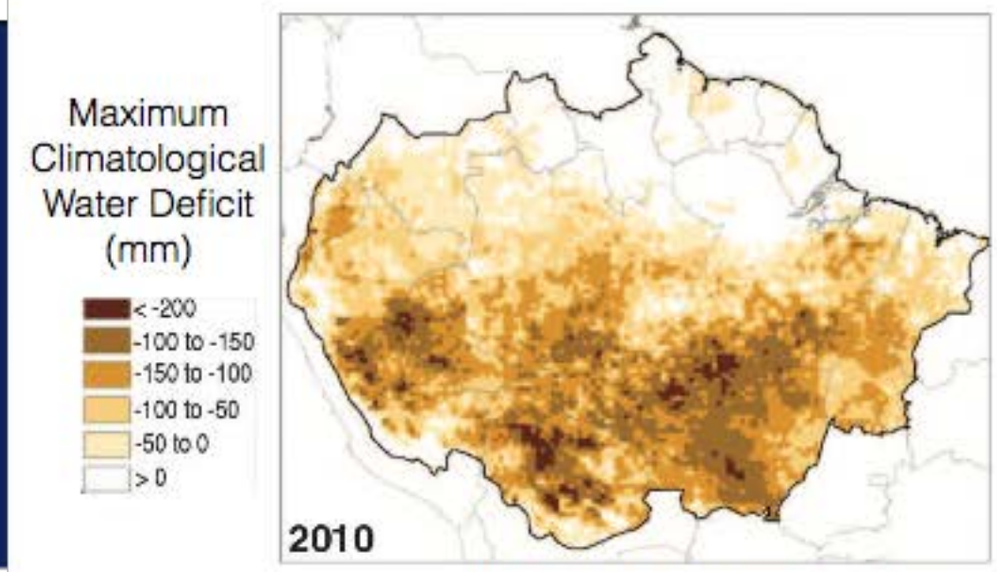
AMAZONIAN ATMOSPHERIC CO_2 DATA SUGGEST MISSING MOISTURE SENSITIVITY IN CARBON-CLIMATE MODELS

Global Monitoring Annual Conference - May 2016

Caroline Alden, John Miller, Anna Harper, Anders Ahlström, Manuel Gloor, Luciana Gatti, Arlyn Andrews, Kirk Thoning, Noah Diffenbaugh, TRENDY modeling group

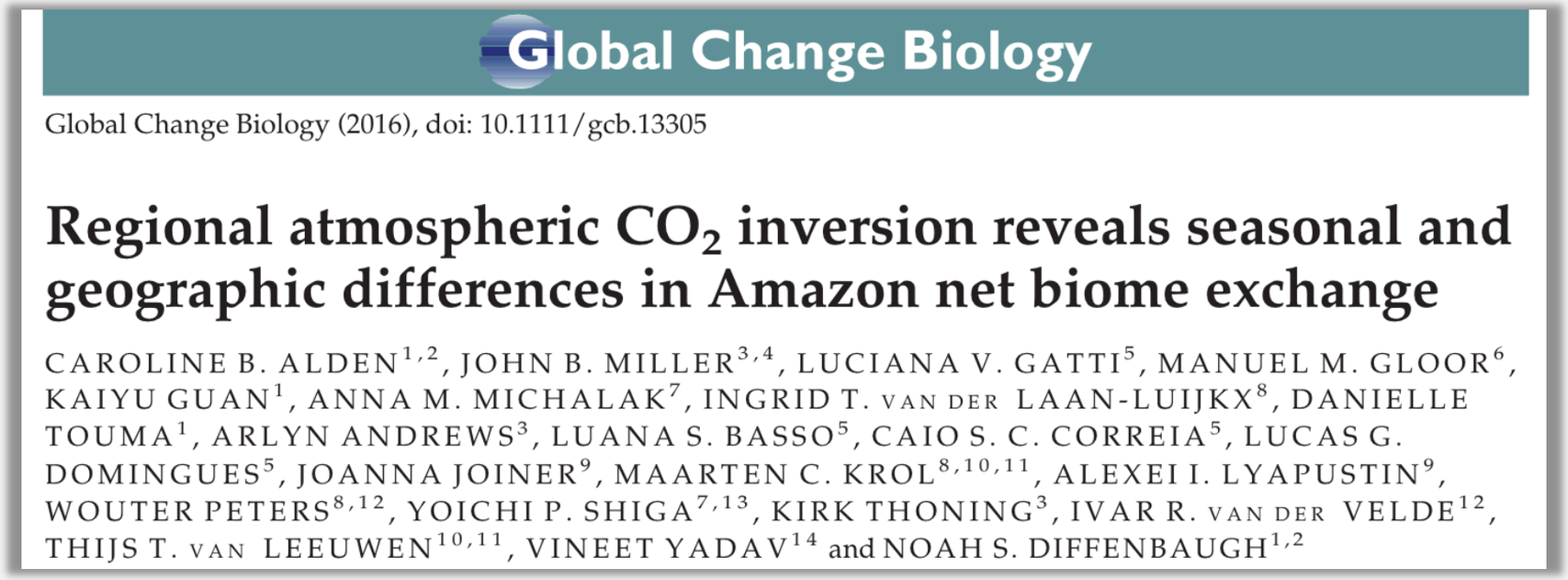


Lewis et al. Nature 2011

TOP-DOWN & BOTTOM-UP ESTIMATES OF AMAZON NET BIOME EXCHANGE (NBE)

- TRENDY models: 8 dynamic global vegetation models (DGVMs), S3 simulation driven by CRU-NCEP reanalysis
- Regional CO_2 inversion: 2010-2012 NBE, largely independent of prior flux estimates, **Aircraft profiles in the Amazon = local CO_2 observations**

Key questions:
Agreement in interannual / seasonal NBE?
Agreement in NBE sensitivity to moisture and temperature?

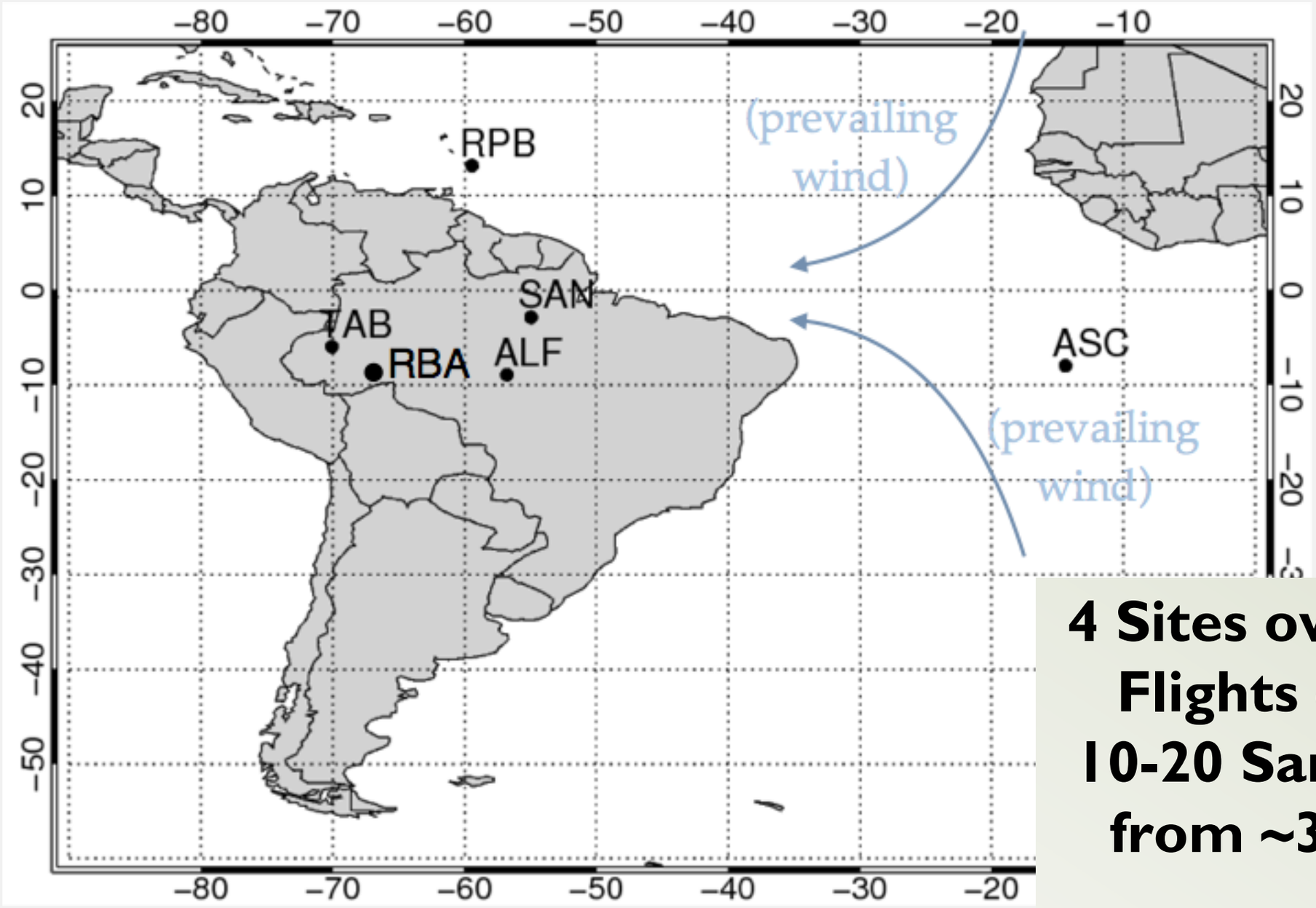

Global Change Biology

Global Change Biology (2016), doi: 10.1111/gcb.13305

Regional atmospheric CO_2 inversion reveals seasonal and geographic differences in Amazon net biome exchange

CAROLINE B. ALDEN[1,2], JOHN B. MILLER[3,4], LUCIANA V. GATTI[5], MANUEL M. GLOOR[6], KAIYU GUAN[1], ANNA M. MICHALAK[7], INGRID T. VAN DER LAAN-LUIJKX[8], DANIELLE TOUMA[1], ARLYN ANDREWS[3], LUANA S. BASSO[5], CAIO S. C. CORREIA[5], LUCAS G. DOMINGUES[5], JOANNA JOINER[9], MAARTEN C. KROL[8,10,11], ALEXEI I. LYAPUSTIN[9], WOUTER PETERS[8,12], YOICHI P. SHIGA[7,13], KIRK THONING[3], IVAR R. VAN DER VELDE[12], THIJS T. VAN LEEUWEN[10,11], VINEET YADAV[14] and NOAH S. DIFFENBAUGH[1,2]

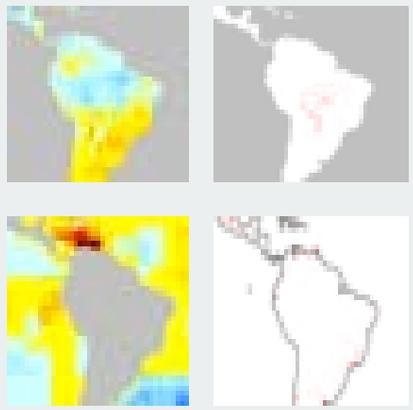
Regional Inverse Modeling



4 Sites over Amazon Basin
Flights every 2-3 weeks
10-20 Samples Each Flight
from ~300 m to 4400 m

2 "boundary" sites
Weekly Sampling

Regional Inverse Modeling



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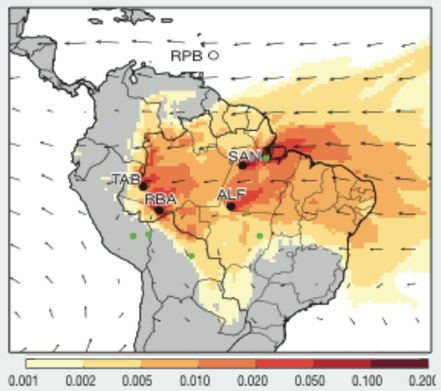

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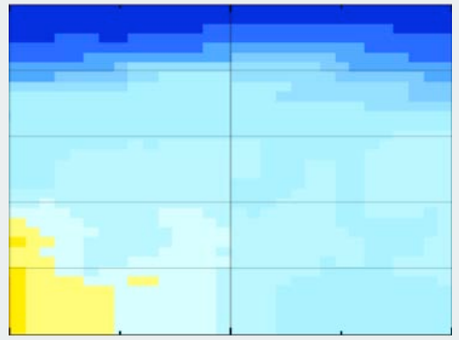

20N 20S

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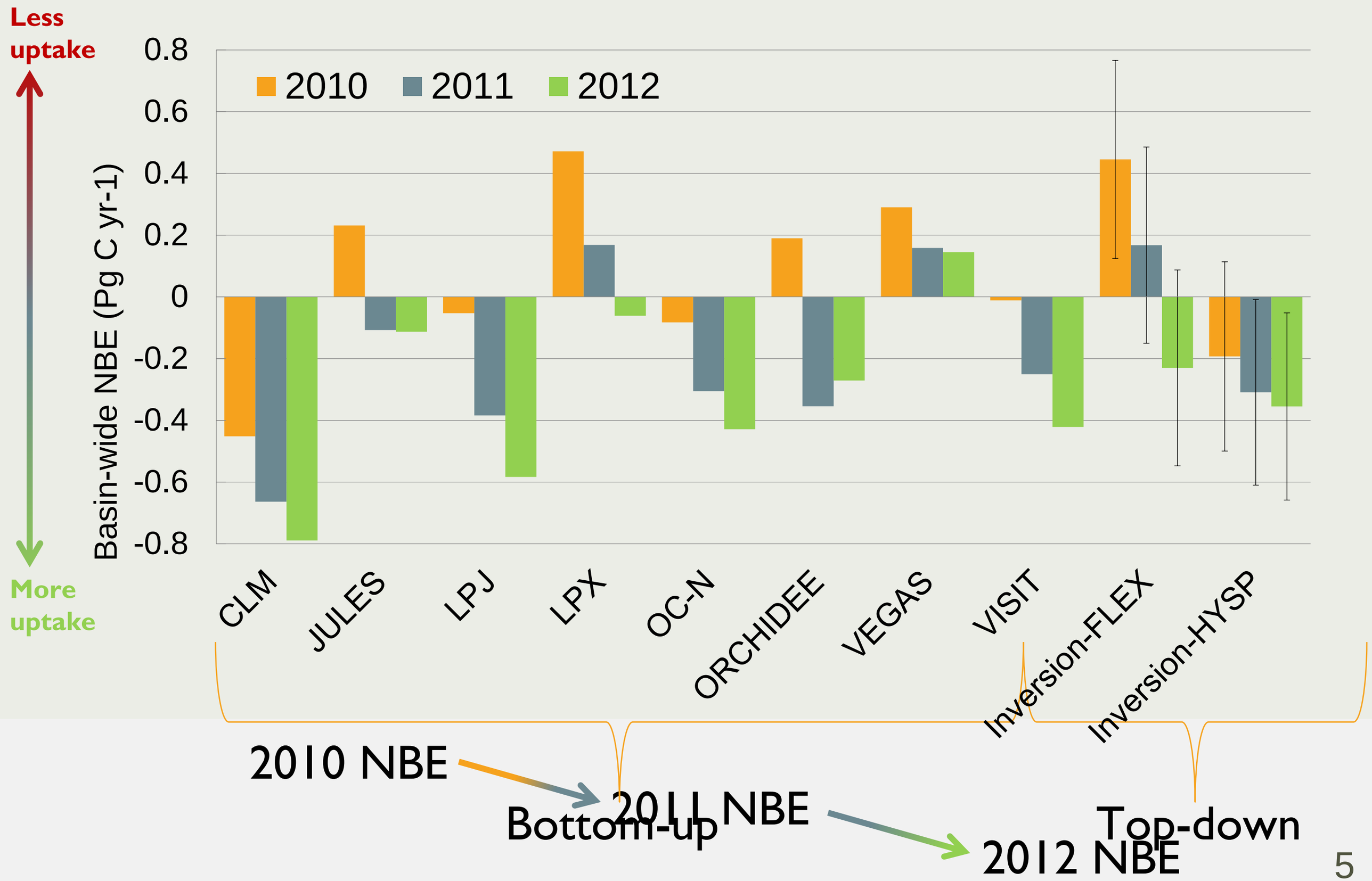
Prior Flux Footprint Background CO_2 Prediction

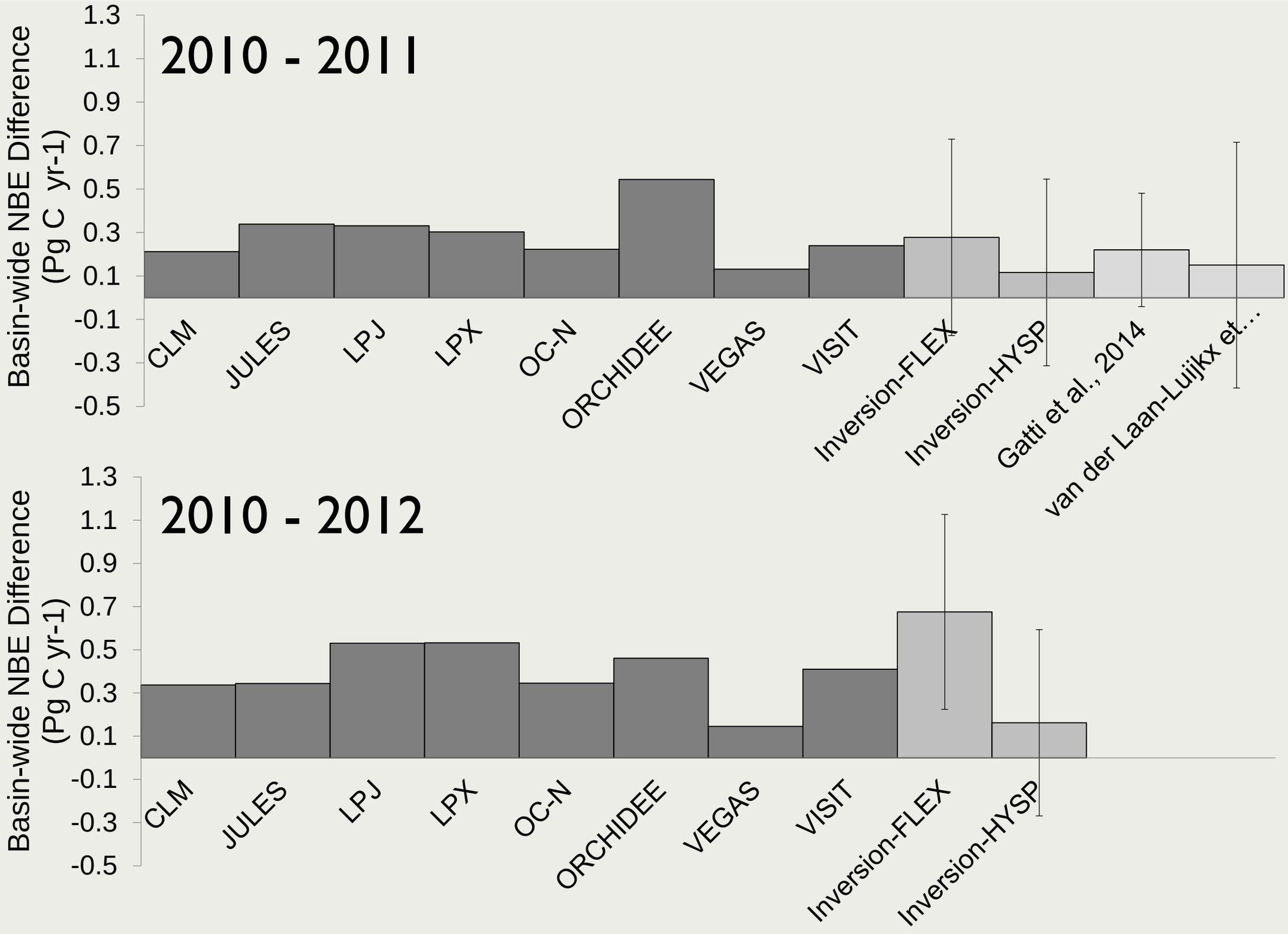
The inversion adjusts fluxes and background to minimize [Predicted – Observed CO_2]

- Prior NBE estimate is neutral (no seasonal or interannual variability)
- Background optimized in inversion
- Transport: 2 Lagrangian particle dispersion models, FLEXPART with GFS 0.5° and HYSPLIT with GFS 0.5° meteorology

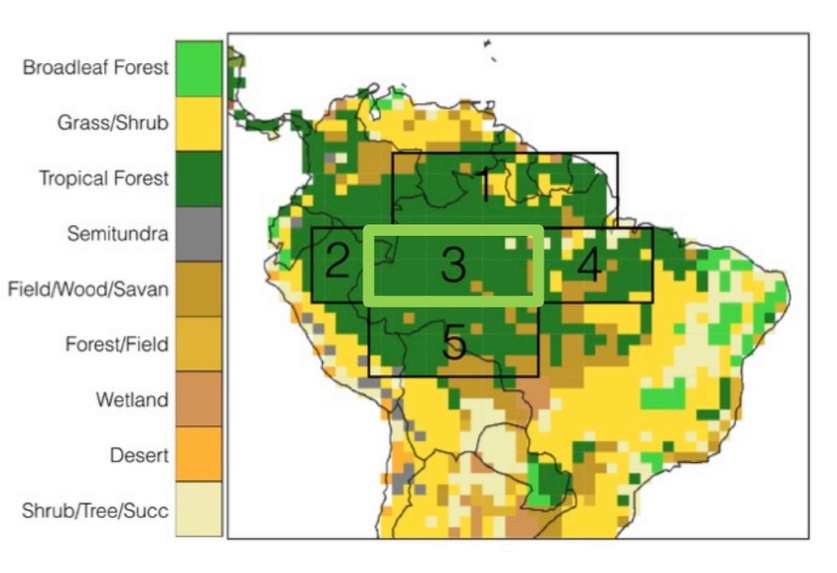
Annual Basin-wide NBE



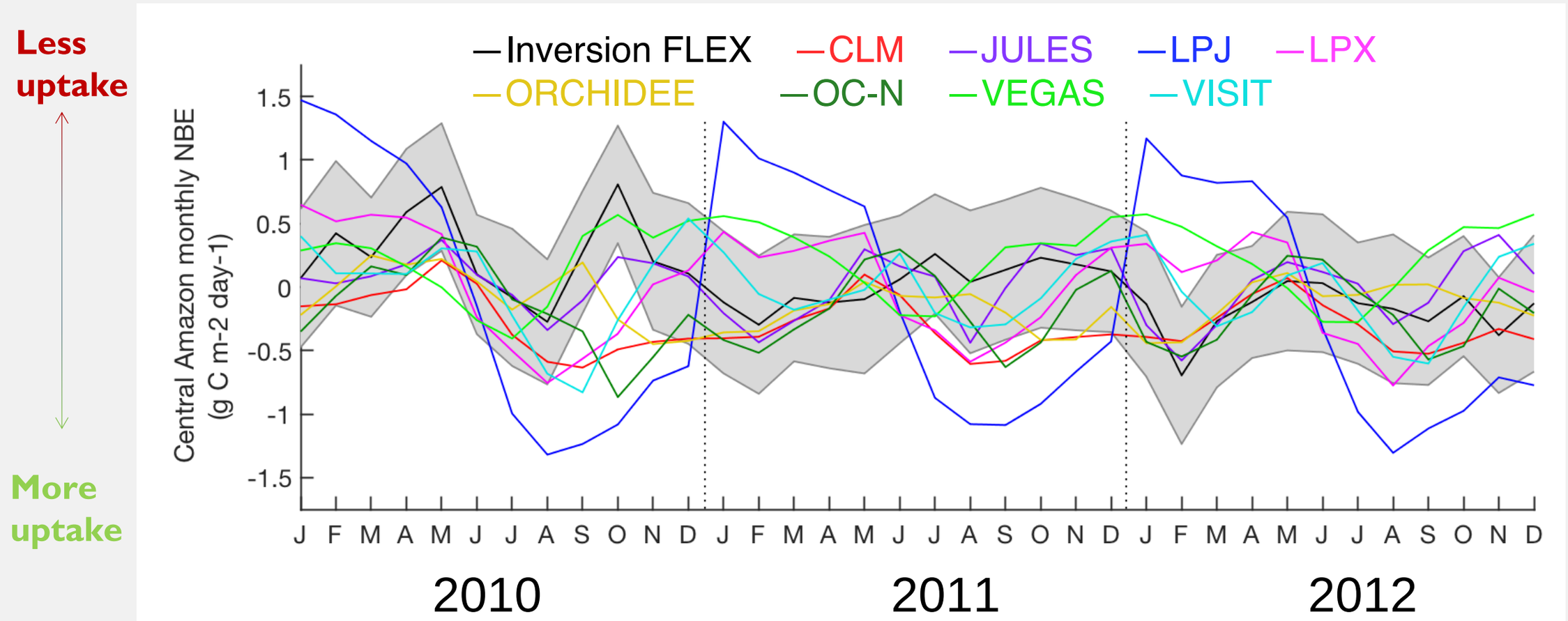
Year-to-year differences in Annual Basin-wide NBE



Regional NBE Seasonality: Central Amazon

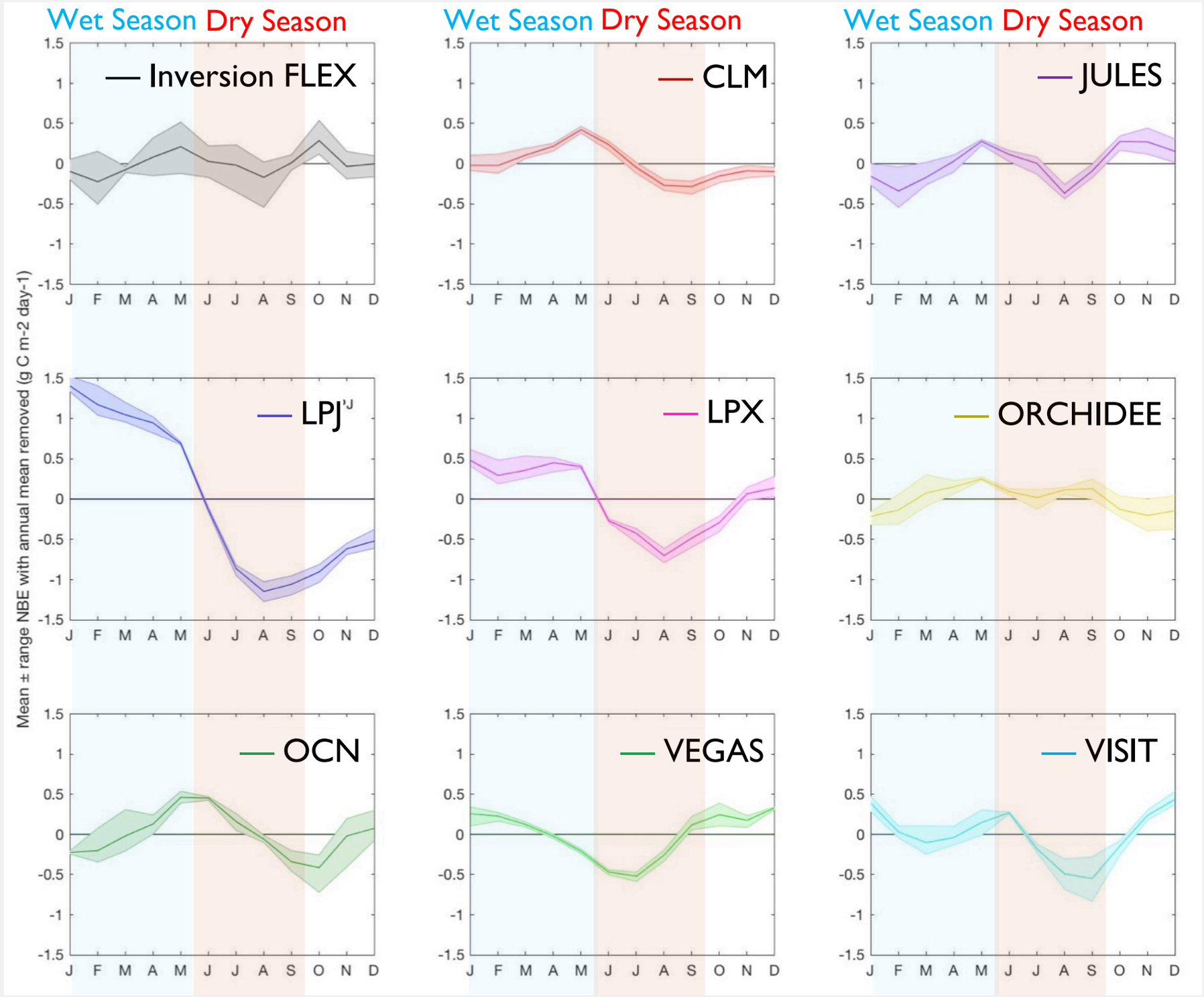


- Inversion NBE seasonality not consistent year to year
- Some models appear to have highly predictable seasonal cycles



Regional NBE Seasonality: Central Amazon

Less uptake



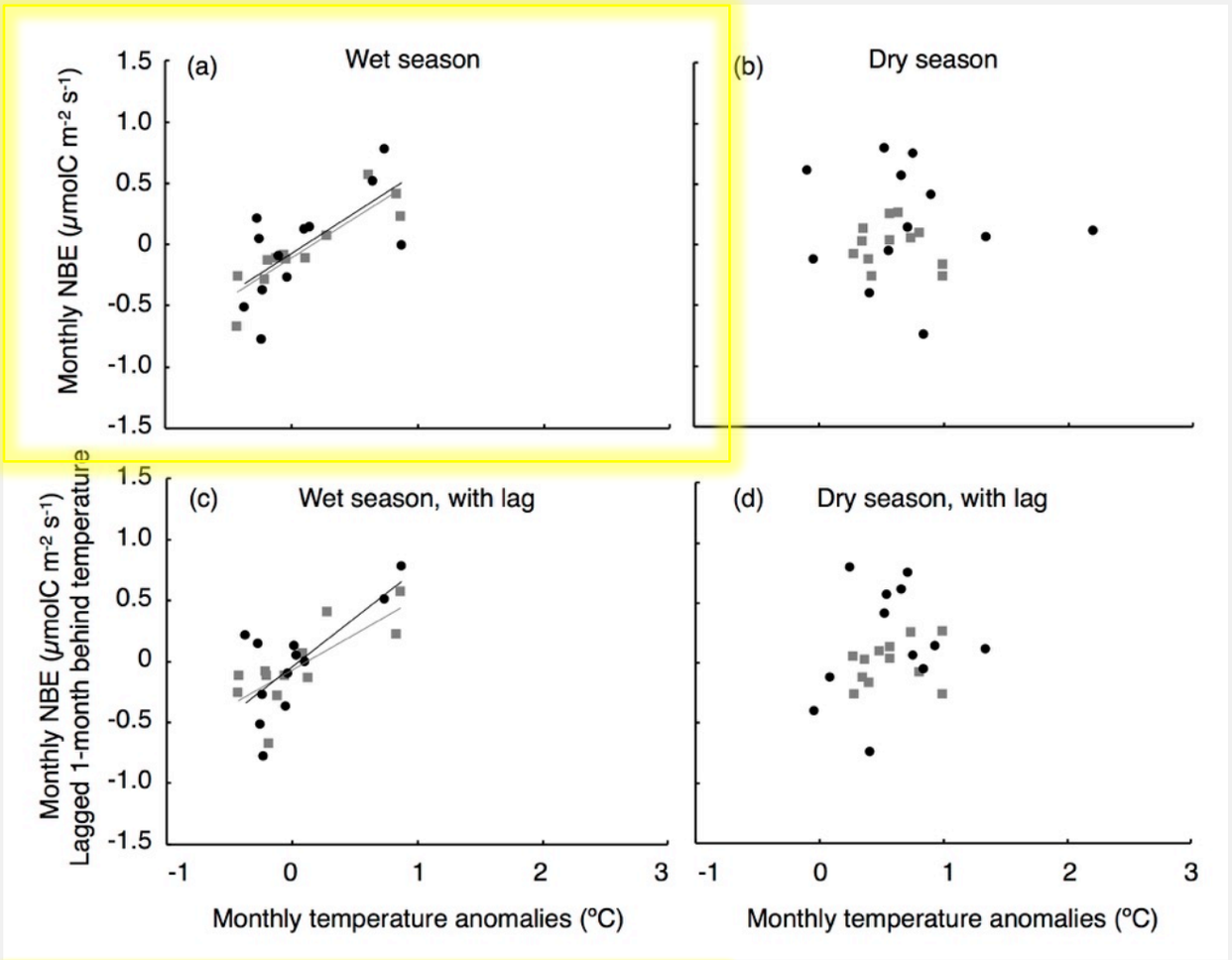
- Top-down: larger differences in monthly NBE values from year to year
- TRENDY: consistent seasonality from year to year
- Wet / Dry season uptake?

More uptake

De-trended mean ± range of 3-year record

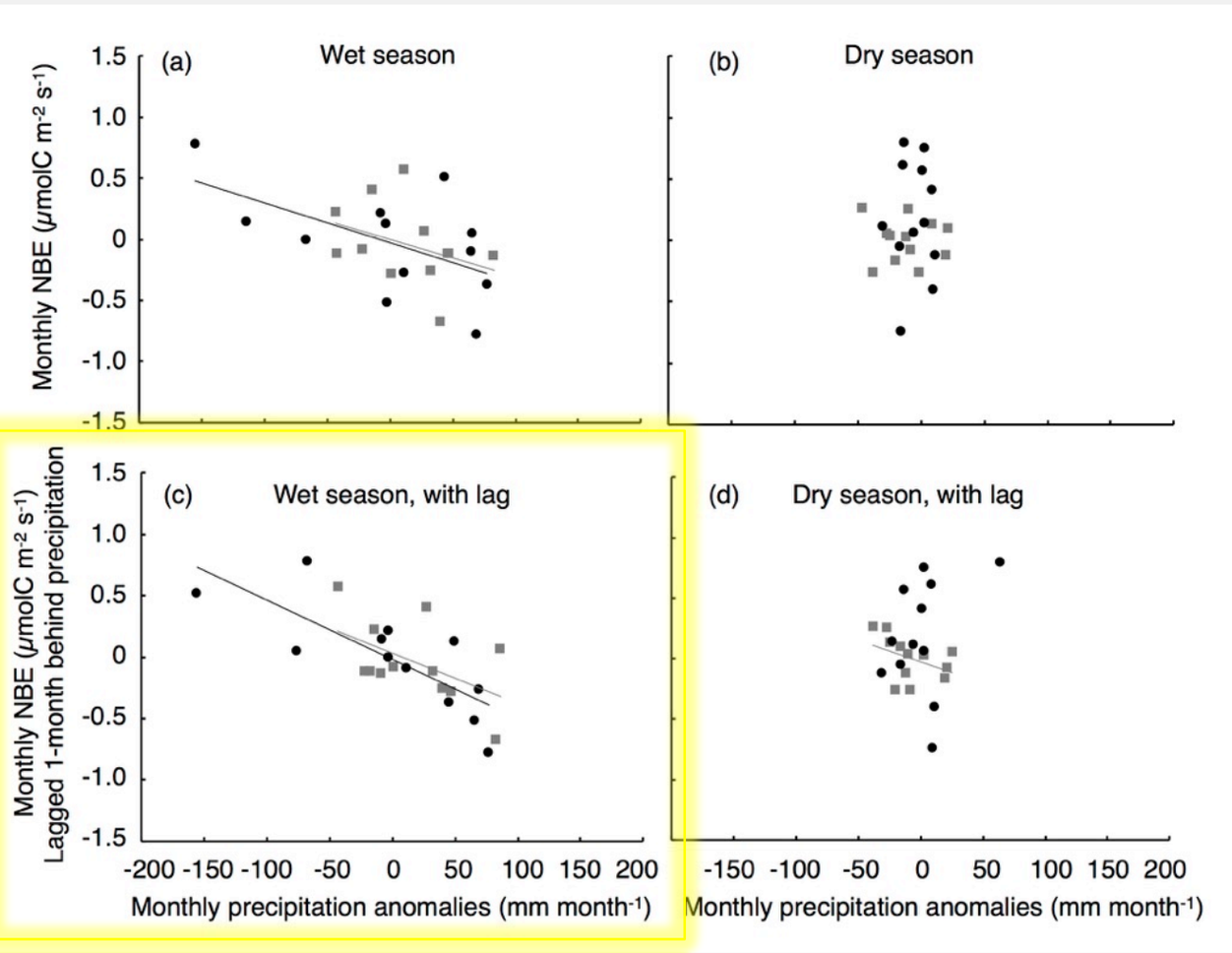
NBE and Climate Anomalies in the wet and dry seasons

NBE vs. NCEP/NCAR Temperature Anomalies



Central Amazon: **R = 0.89**
Eastern Amazon: **R = 0.66**

NBE vs. GPCP Precipitation Anomalies



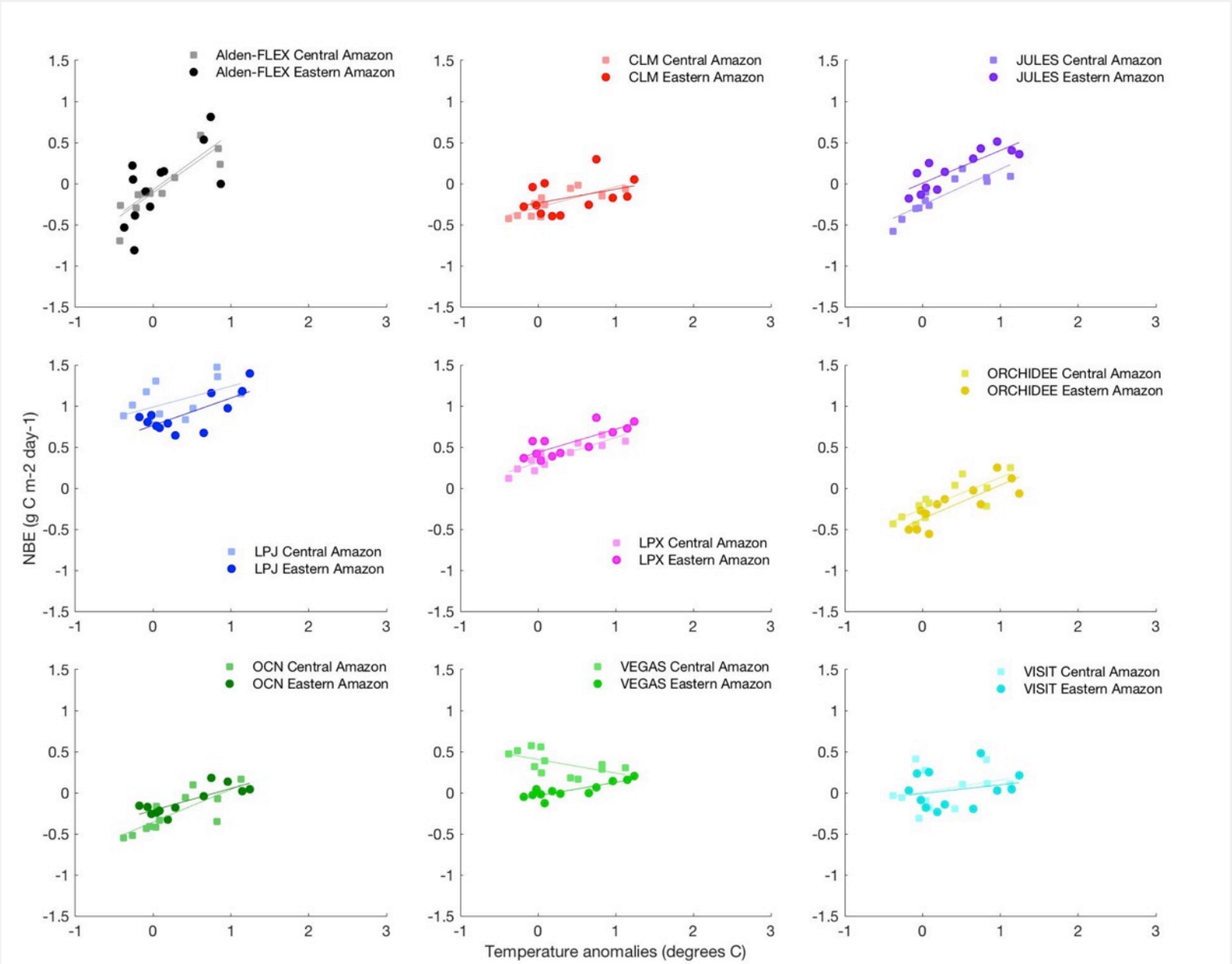
Central Amazon: **R = -0.52**
Eastern Amazon: **R = -0.79**

Alden, Miller, et al. Global Change Biology, 2016

Wet season Temperature Anomalies and NBE

NBE vs. Temperature Anomalies: correlation coefficient R **(Bold if *p*<0.1)**

Temperature Anomalies	Inversion Flexpart	CLM	JULES	LPJ	LPX	ORCH-IDEE	OCN	VEGAS
C. Amazon wet season lag=0	**0.89**	**0.80**	**0.88**	**0.52**	**0.90**	**0.80**	**0.80**	**-0.56**
E. Amazon wet season lag=0	**0.66**	0.40	**0.84**	**0.72**	**0.80**	**0.83**	**0.81**	**0.85**

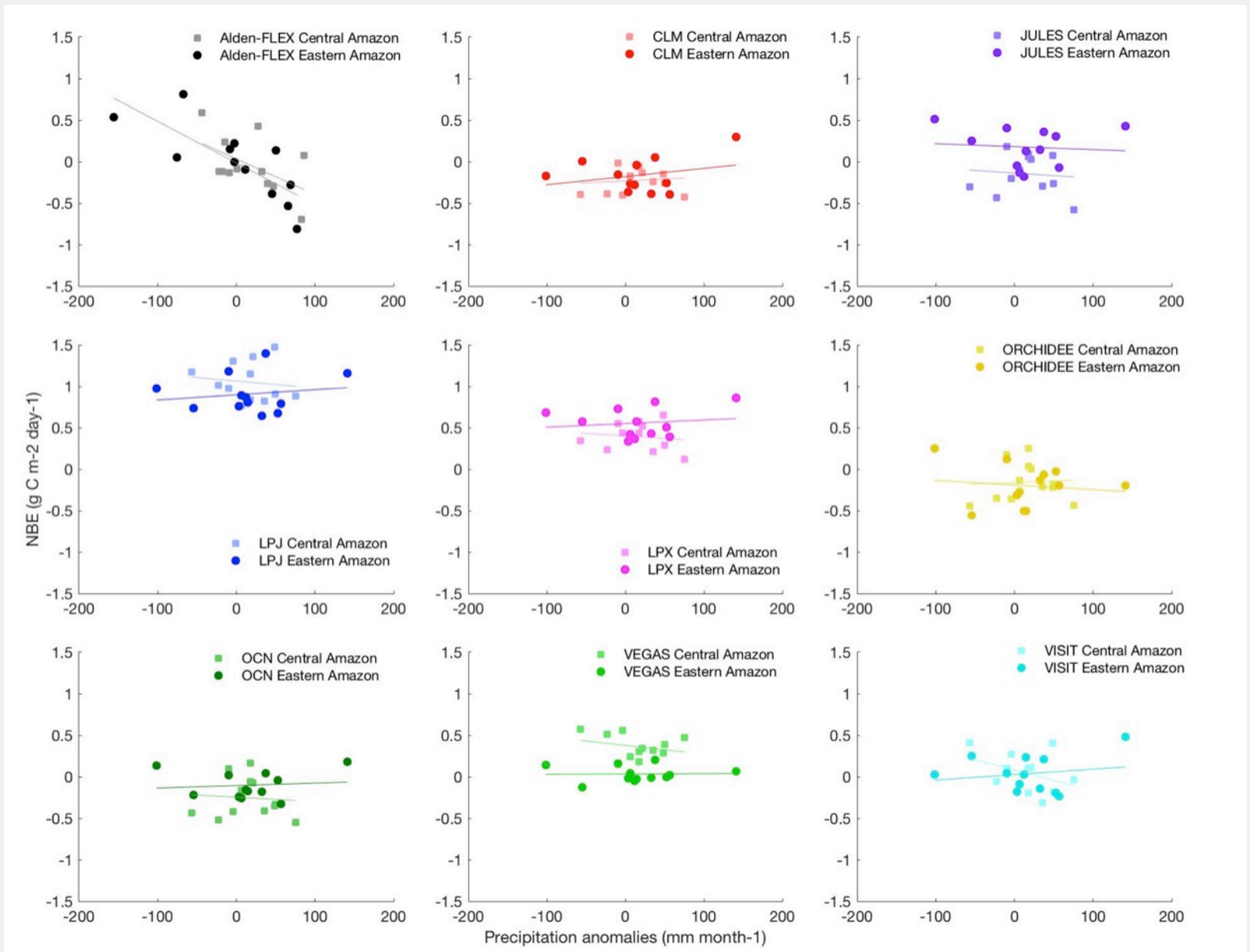


- Wet season temperature sensitivity well-represented by most models

Wet season Precipitation Anomalies and NBE

NBE vs. Precipitation Anomalies: correlation coefficient R **(Bold if p<0.1)**

	Inversion Flexpart	CLM	JULES	LPJ	LPX	ORCH-IDEE	OCN	VEGAS
C. Amazon wet season lag=0	-0.36	**-0.51**	**-0.52**	-0.02	-0.40	**-0.57**	**-0.50**	0.44
E. Amazon wet season lag=0	**-0.57**	-0.13	-0.44	-0.34	-0.38	-0.36	-0.36	-0.34
C. Amazon wet season lag=1	**-0.52**	0.11	-0.10	-0.13	-0.14	0.05	-0.08	-0.27
E. Amazon wet season lag=1	**-0.79**	0.28	-0.09	0.16	0.14	-0.13	0.10	0.03



- Wet season 1-month lag not represented by models
- Some models capture precipitation sensitivity without lag

Conclusions

Seasonality of Amazon NBE

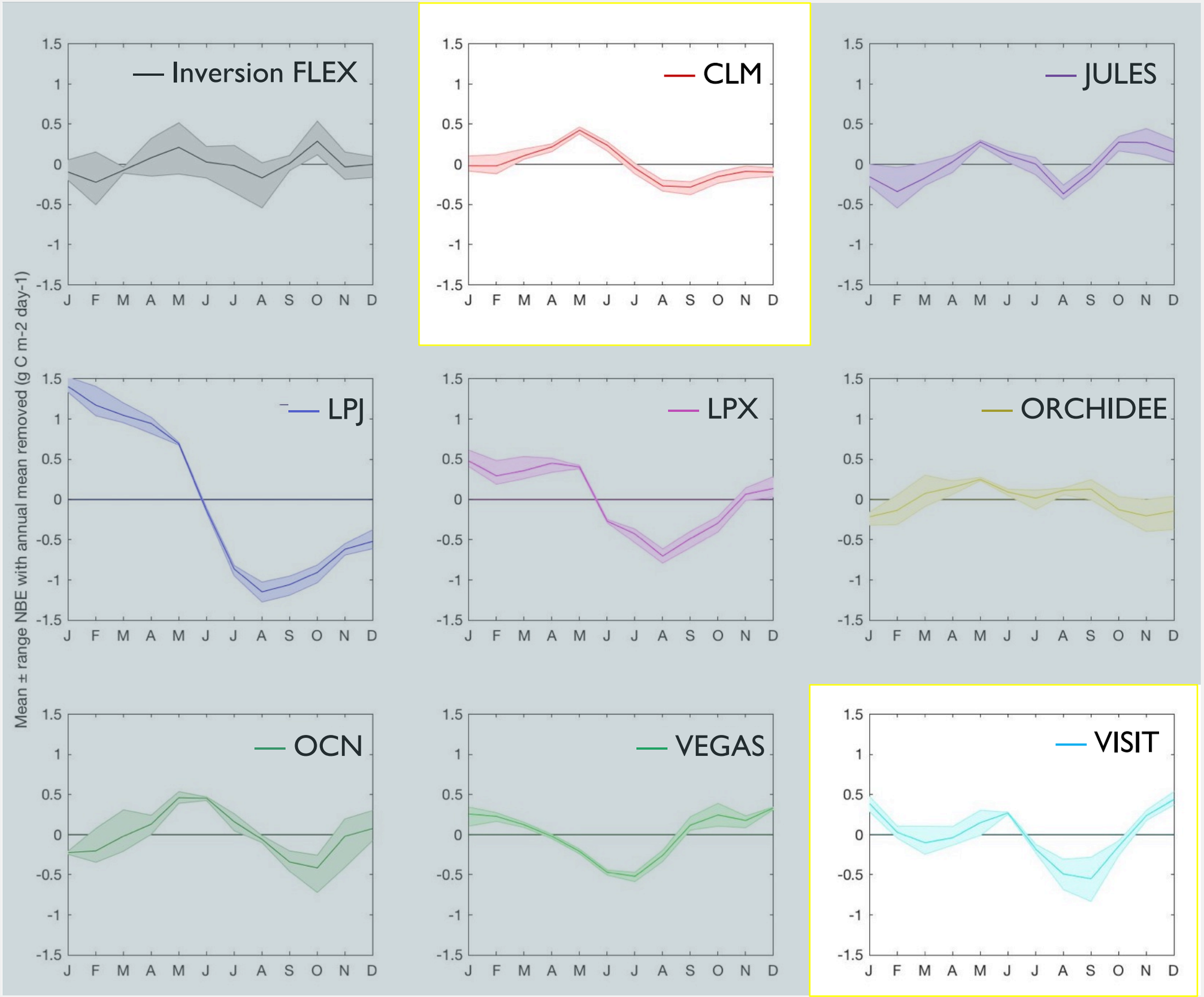
- TRENDY models predict more "predictable" seasonal cycle than CO_2 inversion suggests
- TRENDY models agree with CO_2 observations on dry season uptake (but for different reasons GPP ↑ Resp.↓)

Amazon NBE and Climate Anomalies

- Wet season NBE temperature sensitivity: TRENDY models capture signal seen by inversion
- Wet season NBE precipitation sensitivity: TRENDY models do *not* appear to represent observed relationship between precipitation anomalies and NBE in the following month

Regional NBE Seasonality: Central Amazon

Less uptake

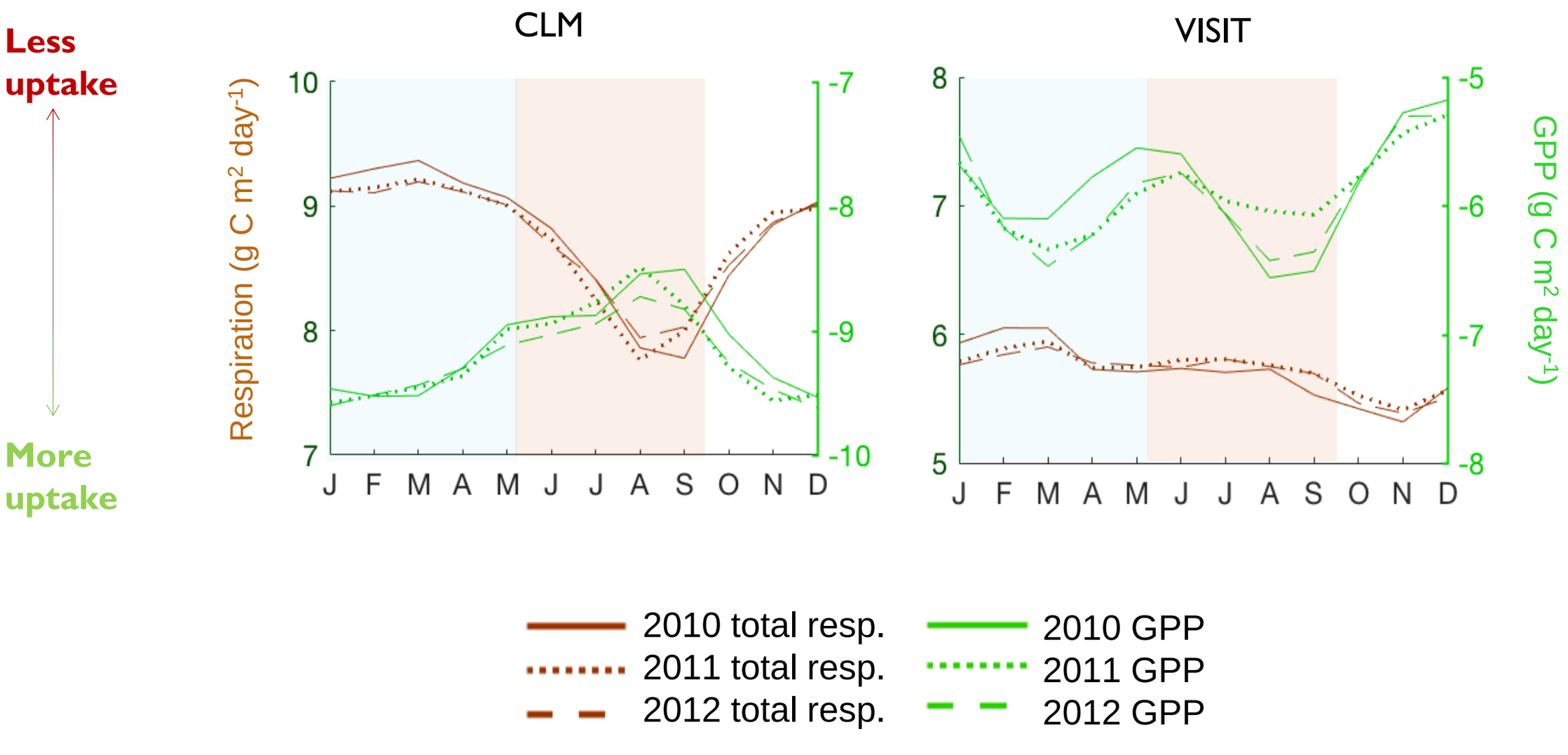


More uptake

De-trended mean ± range of 3-year record

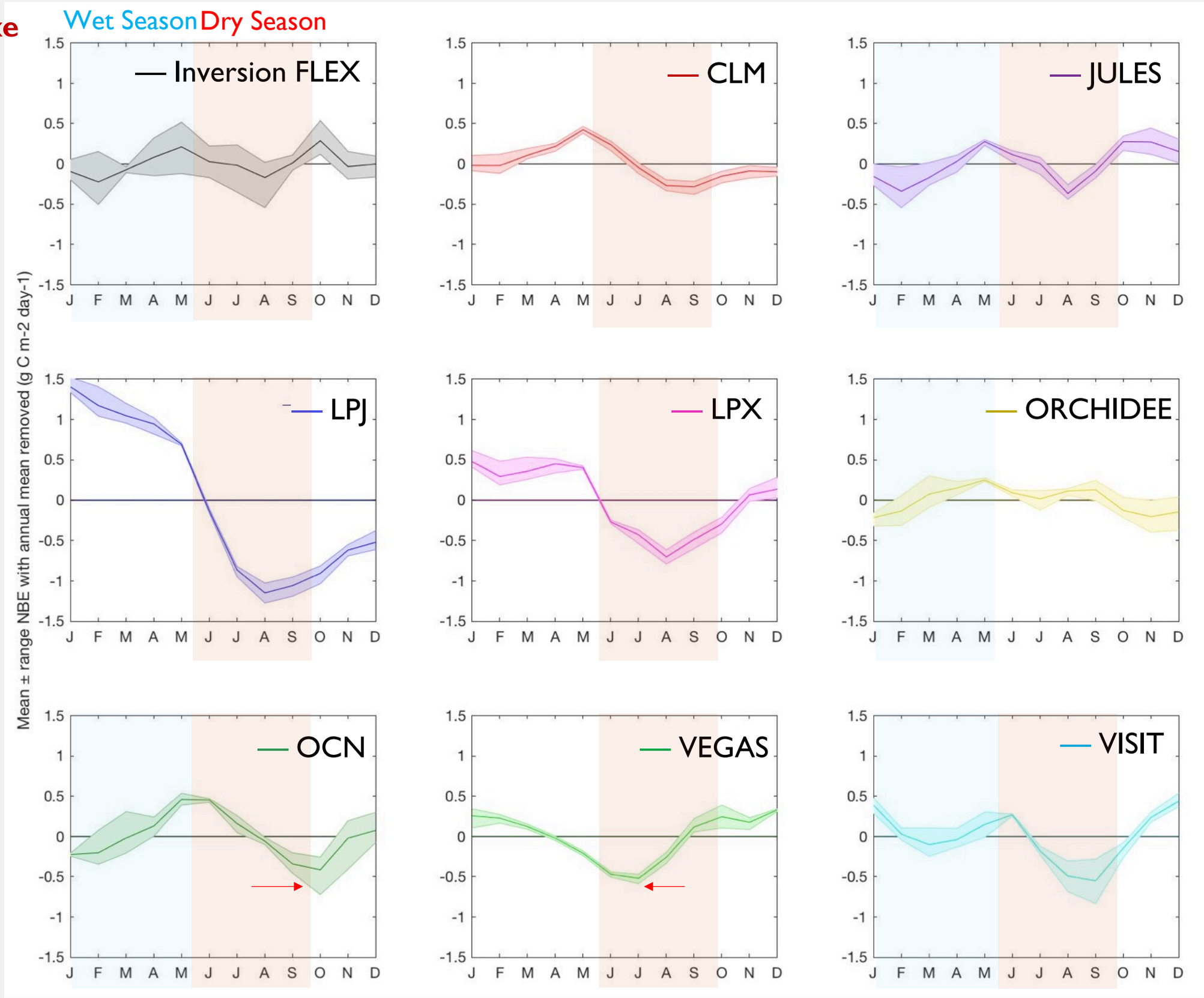
Regional NBE Seasonality: Central Amazon

Both models: wet season net carbon uptake driven by GPP increase
Dry season net uptake:
CLM: Respiration decrease, GPP decrease
VISIT: Respiration no change, GPP increase



Regional NBE Seasonality: Central Amazon

Less uptake



More uptake

- Inversion: wet season and dry season uptake?
- Some TRENDY models show similar signal of wet season uptake
- Most TRENDY models show dry season uptake

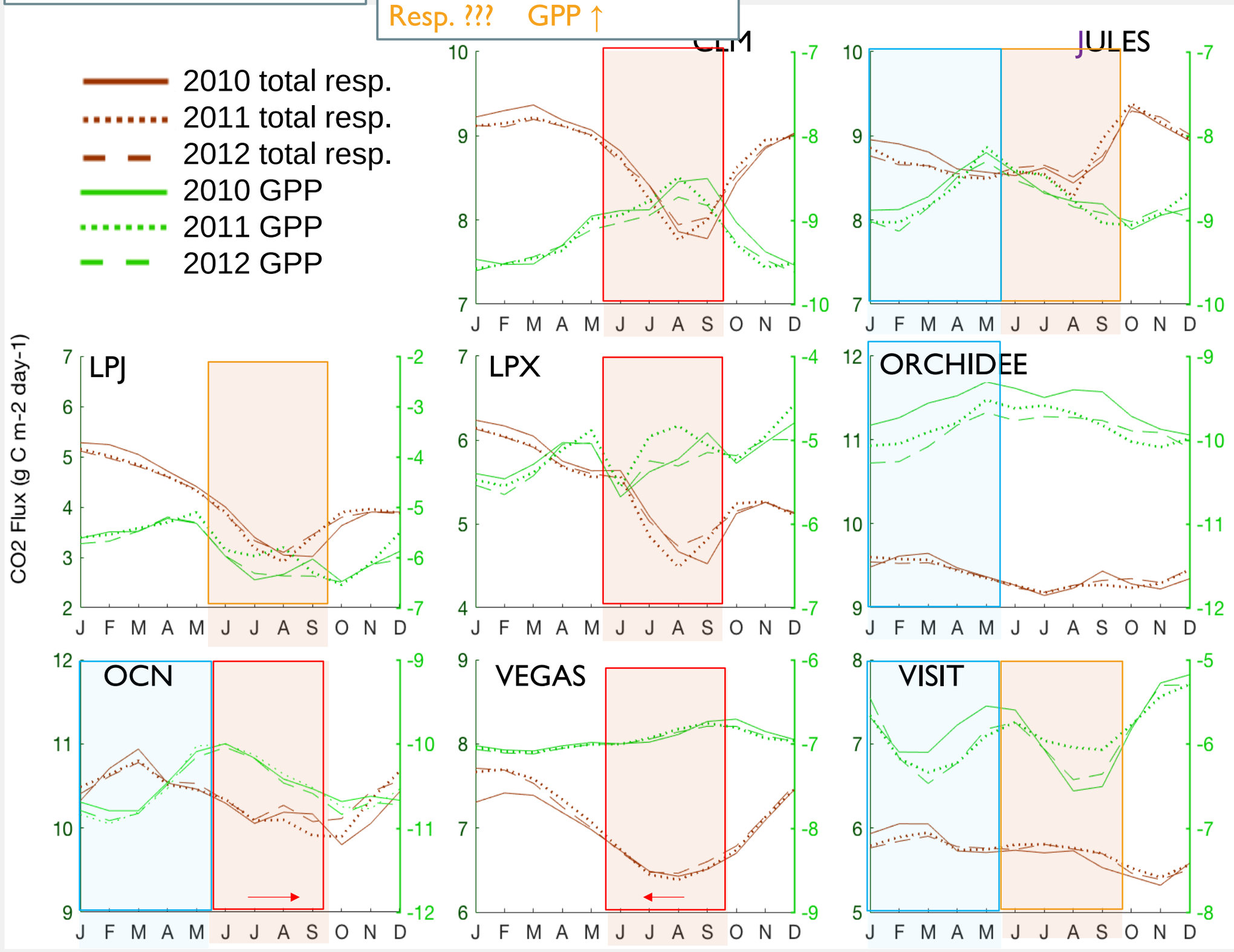
Mean ± range of 3-year record with each year annual mean subtracted

Regional NBE Seasonality: Central Amazon

Less uptake

Wet season C uptake:
Resp. ↑ GPP ↑

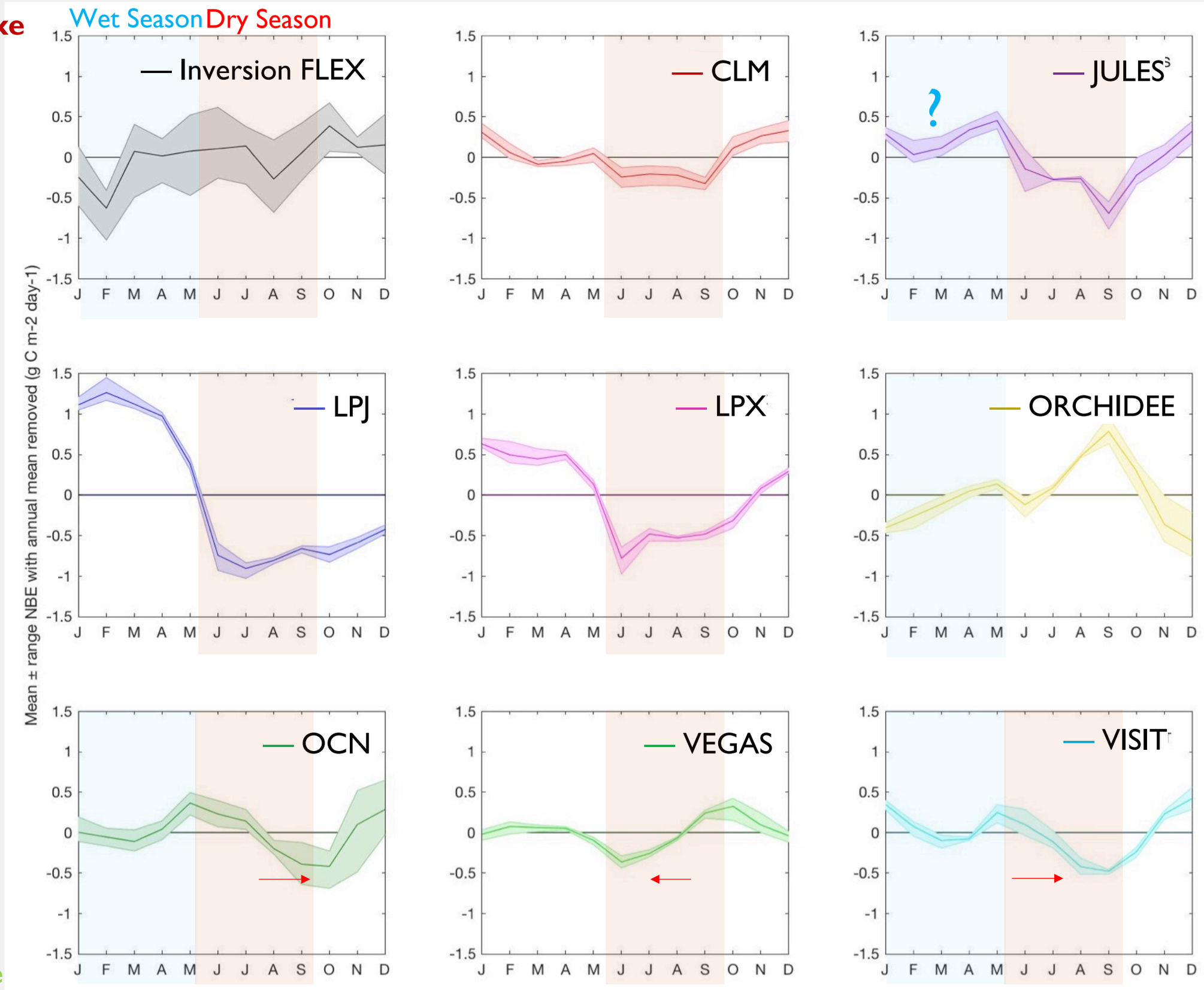
Dry season C uptake:
Resp. ↓ GPP ↓
Resp. ??? GPP ↑



More uptake

Regional NBE Seasonality: Eastern Amazon

Less uptake



More uptake

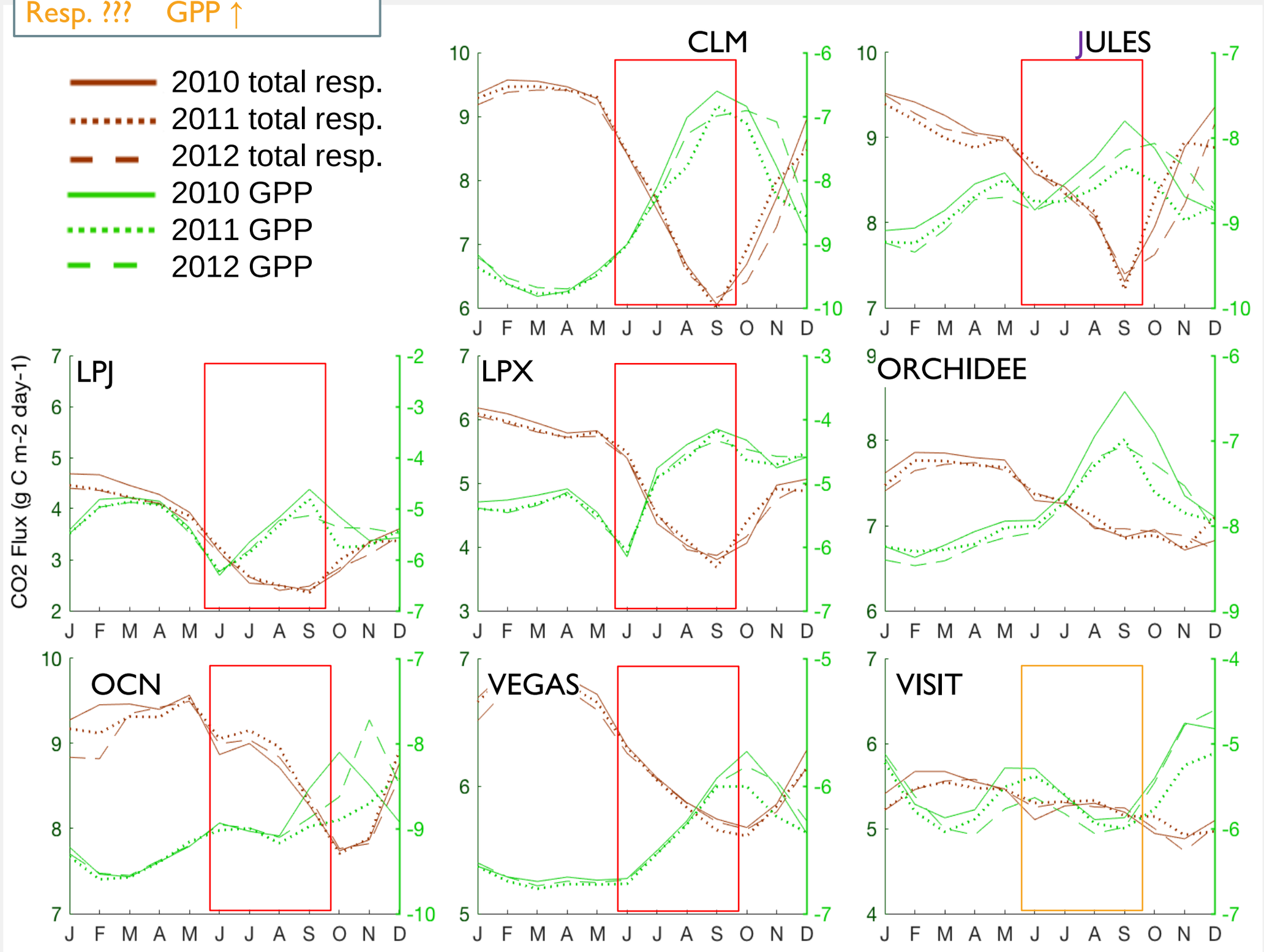
- Inversion: wet season and dry season uptake
- Few TRENDY models show similar signal of wet season uptake
- Most TRENDY models show dry season uptake

Mean ± range of 3-year record with each year annual mean subtracted

Regional NBE Seasonality: Eastern Amazon

Less uptake

Dry season C uptake:
Resp. ↓ GPP ↓
Resp. ??? GPP ↑



More uptake

Temperature Anomalies	Flexpart & NCEP/NCAR R1	CLM	JULES	LPJ	LPX	ORCH-IDEE	OCN	VEGAS
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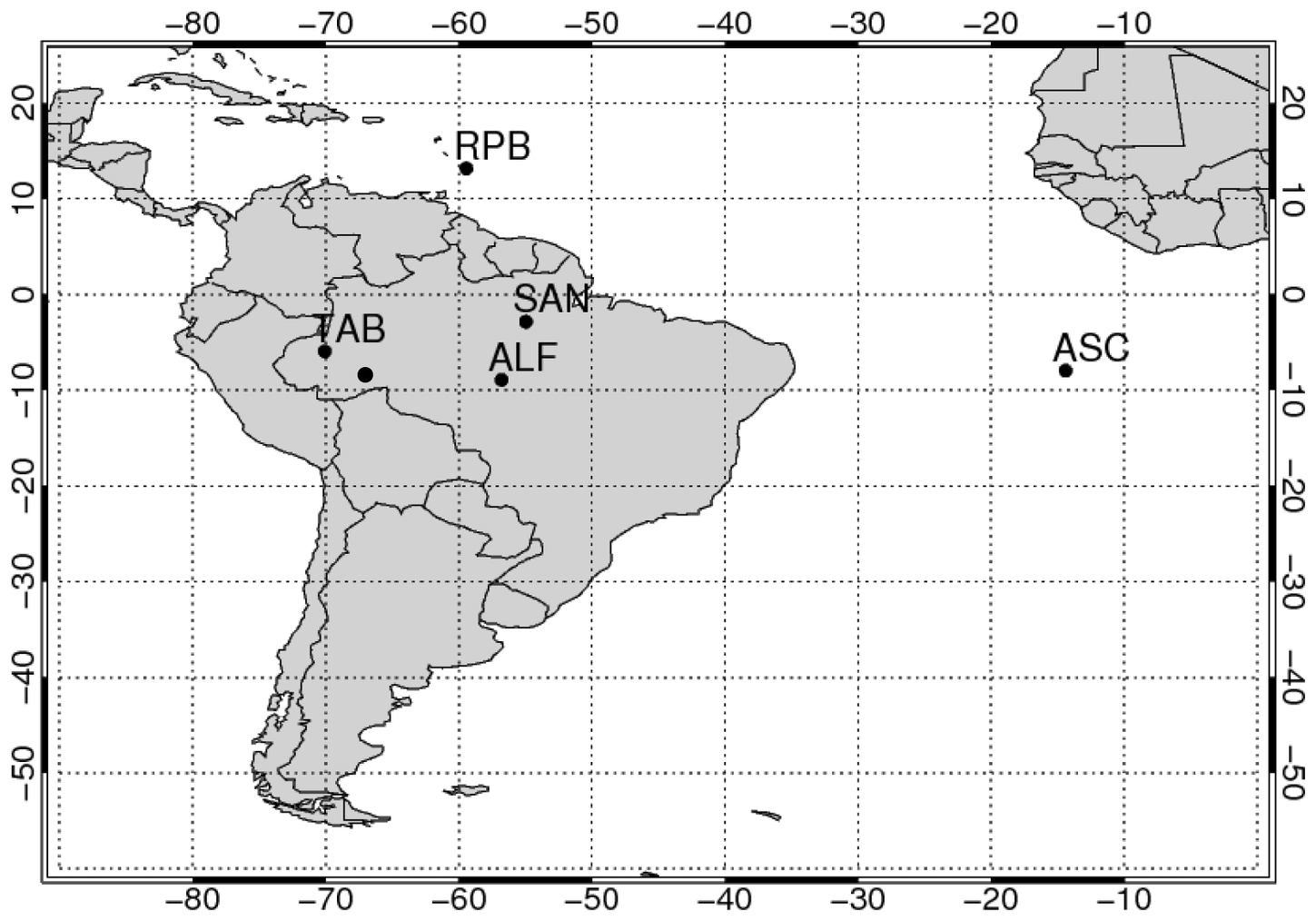
E. Amazon wet season lag=0	**0.66**	0.40	**0.84**	**0.72**	**0.80**	**0.83**	**0.81**	**0.85**
C. Amazon wet season lag=1	**0.76**	0.41	**0.53**	0.32	**0.54**	**0.56**	**0.68**	-0.15
E. Amazon wet season lag=1	**0.72**	0.19	**0.64**	0.46	**0.54**	**0.53**	0.47	**0.55**
C. Amazon dry season lag=0	-0.17	**-0.49**	-0.18	-0.32	-0.08	**0.51**	-0.47	**0.81**
E. Amazon dry season lag=0	0.02	0.29	0.10	0.32	**0.85**	**0.60**	0.01	**0.51**
C. Amazon dry season lag=1	0.25	-0.30	-0.16	-0.18	0.03	-0.21	-0.45	0.43
E. Amazon dry season lag=1	0.20	-0.02	-0.15	0.51	-0.31	0.11	-0.06	0.12

ackground



Uncertainty

Model-data Mismatch:

R (ppm^2) = σ^2 msmts + σ^2 transport + σ^2 background sampling + σ^2 "other" fluxes + σ^2 representation

σ^2 measurements = σ^2 msmts made at IPEN (0.01 ppm^2) + σ^2 scale btwn IPEN & NOAA (0.01 ppm^2)
σ transport = std dev of differences between influence of land + fire fluxes simulated by flexpart & hysplit, at each site and for each altitude bin
σ background sampling = std dev of differences btwn background curtain sampled with flexpart & hysplit
σ^2 "other" (fire) fluxes = variance in biomass burning emissions (estimated from results of van der Laan-Luijkx et al. (2015) propagated into atmospheric mole fraction uncertainty through $H*Q_{fire}*H^T$.
σ^2 "other" (fossil & ocean) fluxes and representation errors = increased σ by to include these sources

Diagonal Matrix (no spatial or temporal correlation between measurements)

Prior Flux Uncertainty:

Prior flux uncertainty varies in space (1°x1°), but not through time (seasonality not well known)
σ^2 prior flux = (ann mean monthly heterotrophic respiration from GFEDv3.1)^2 + (std dev if differences btwn ann mean SiBCASA and CASA-GFED diurnal cycles)^2

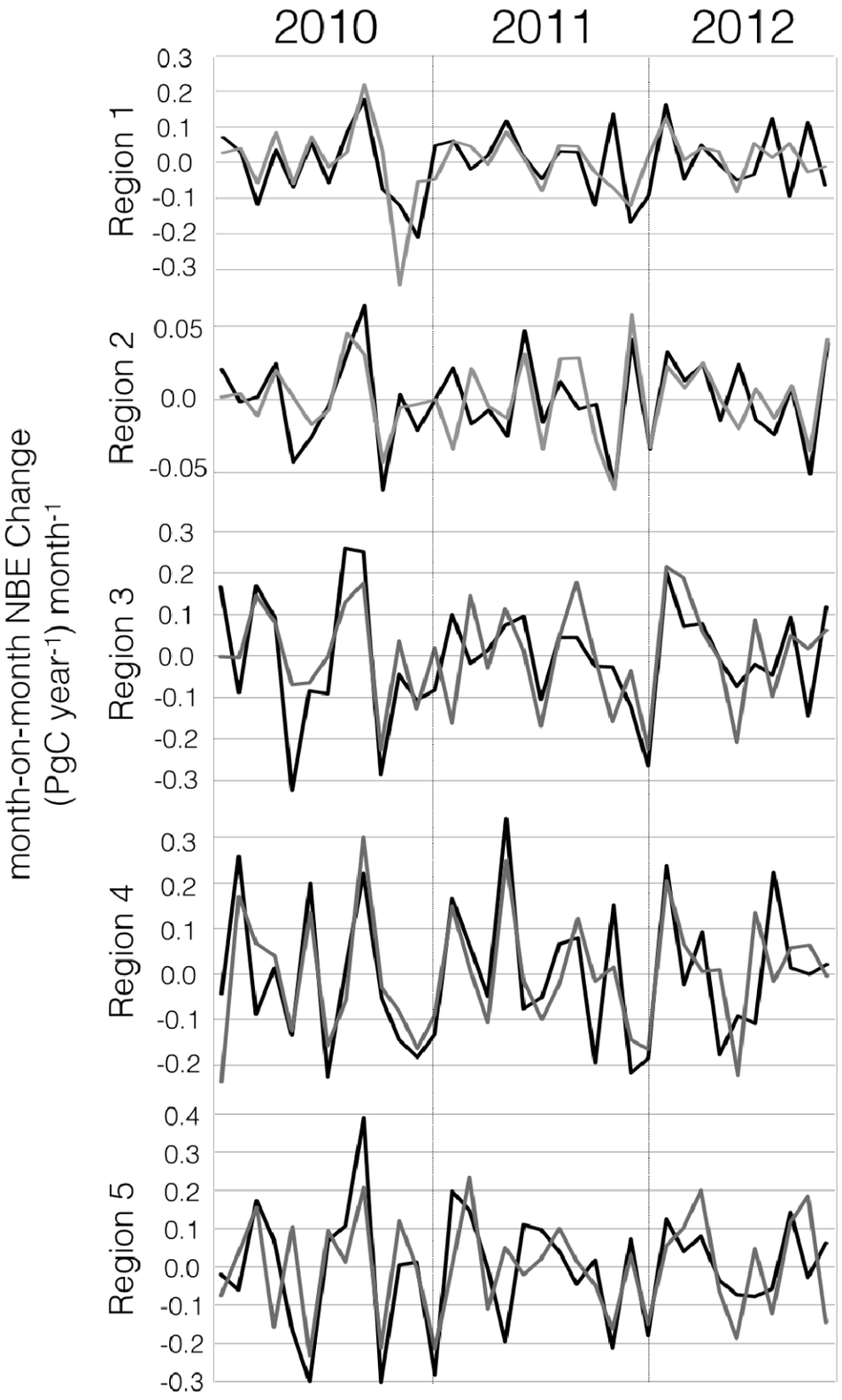
Spatial Correlation length: 300 km
Temporal Correlation length: 5 days

Background Uncertainty:

σ^2 Background = (std dev of historical differences between observations at ASC, RPB or FTL, according to latitude and altitude)^2 + (std dev of differences between sampled CT2013_ei 4D field* and boundary curtain sampled at same latitude)^2
*only added for mean particle trajectories that did not leave the domain

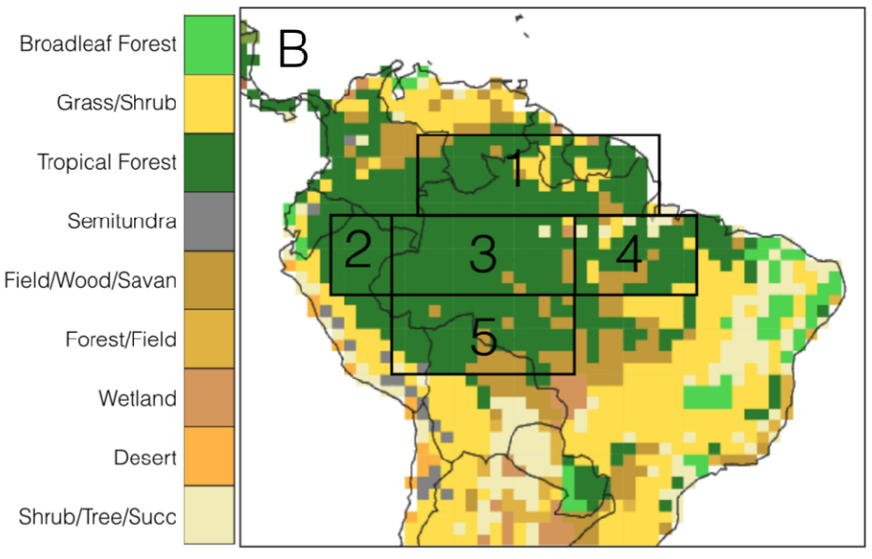
Spatial Correlation length: 1000 km
Temporal Correlation length: 7 days

Month-on-month changes in net biome exchange also similar



— FLEXPART

— HYSPLIT



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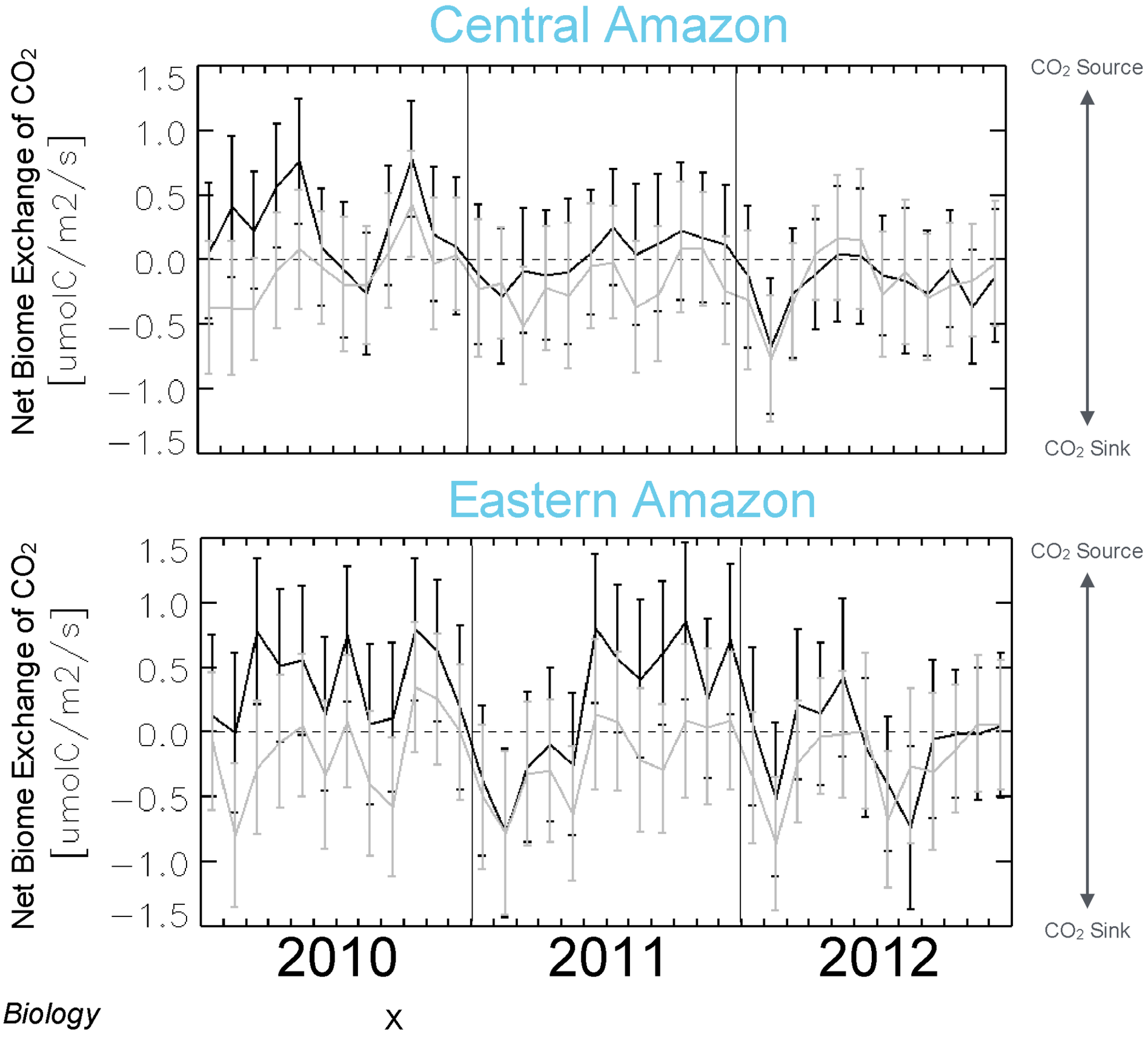
Alden et al.,
in review at *Global Change Biology*

Patterns of flux variability very similar; magnitude different

— FLEXPART

— HYSPLIT



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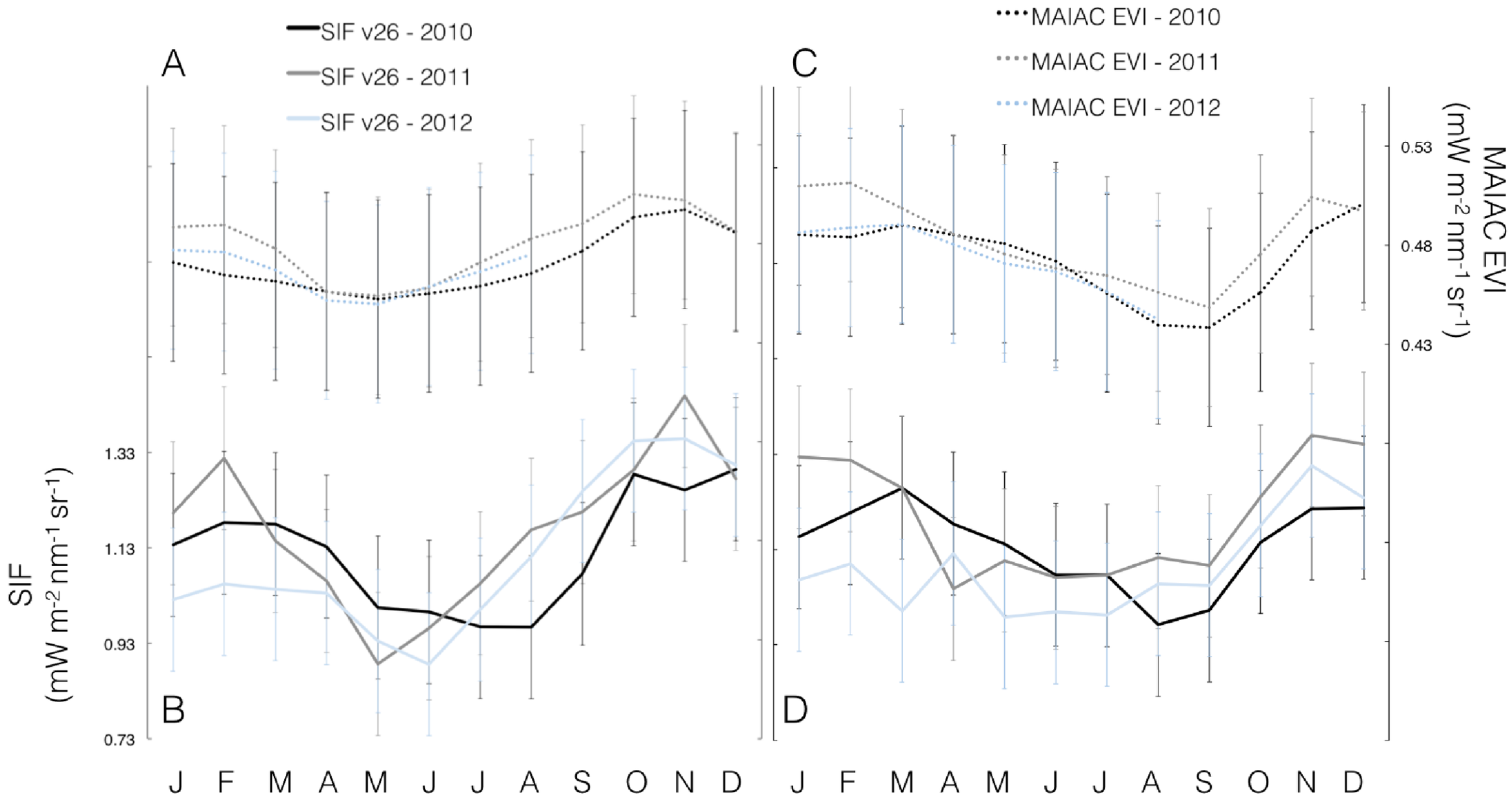
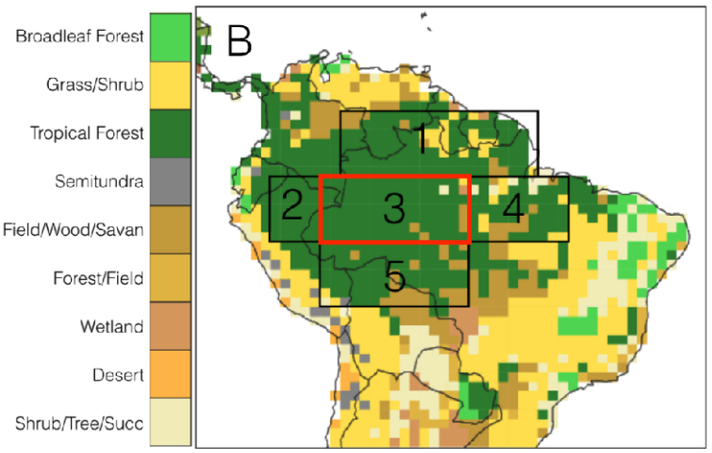
Satellite SIF & EVI



Region 3

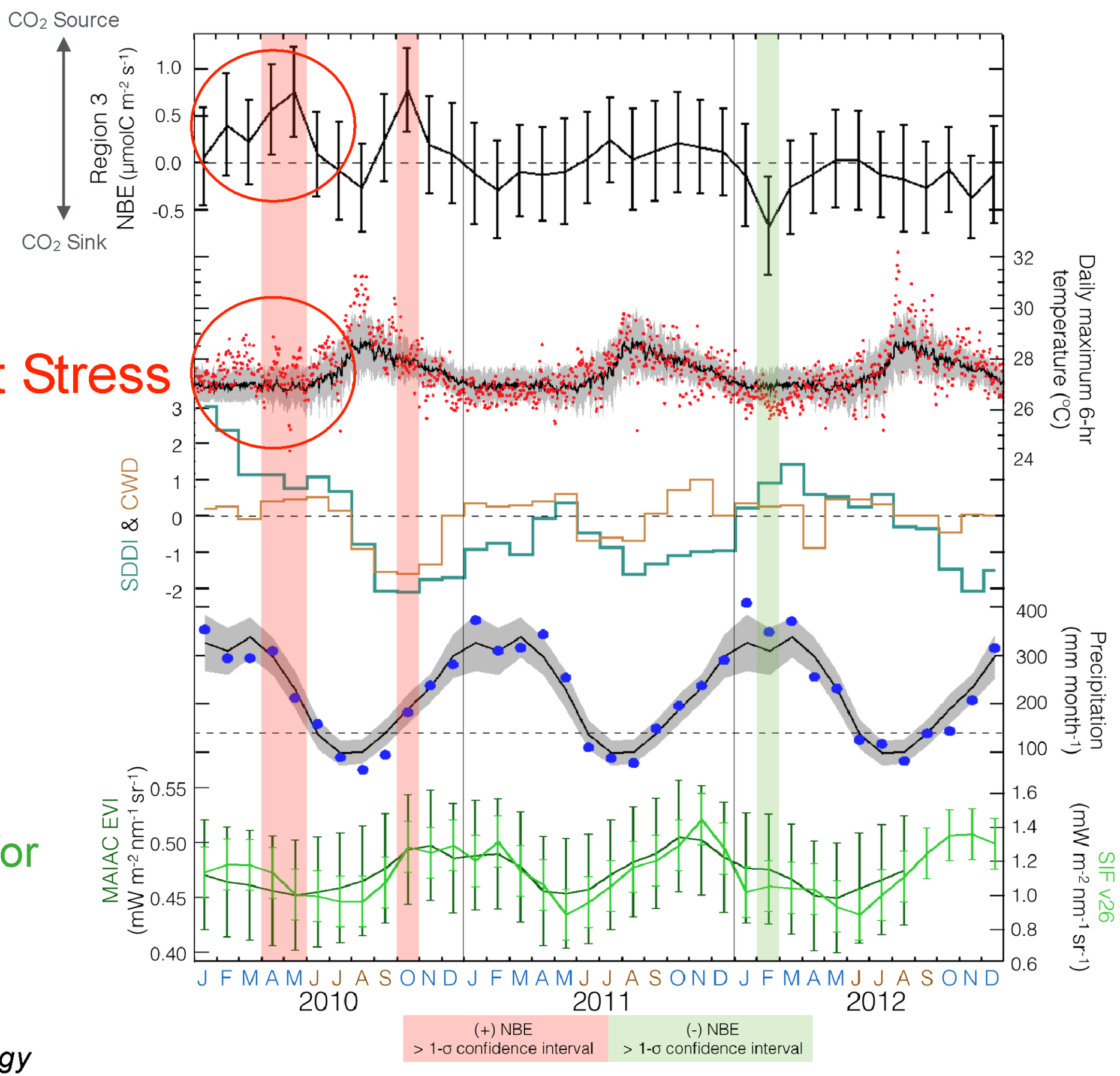
Region 4

Central Amazon monthly Net Biome Exchange



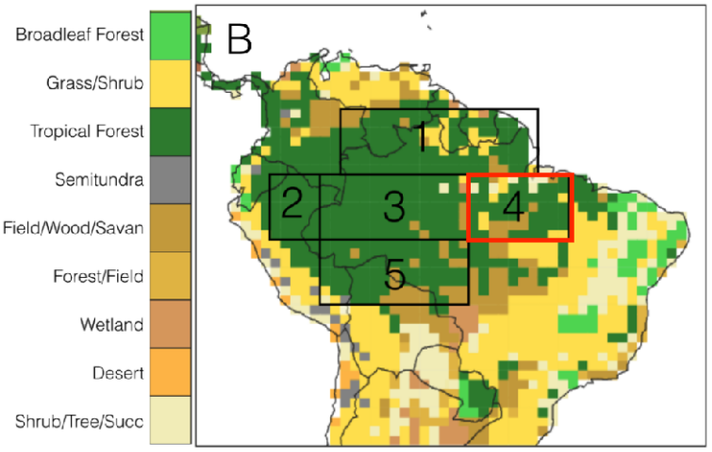
Wet Season Heat Stress

No clear evidence for GPP suppression



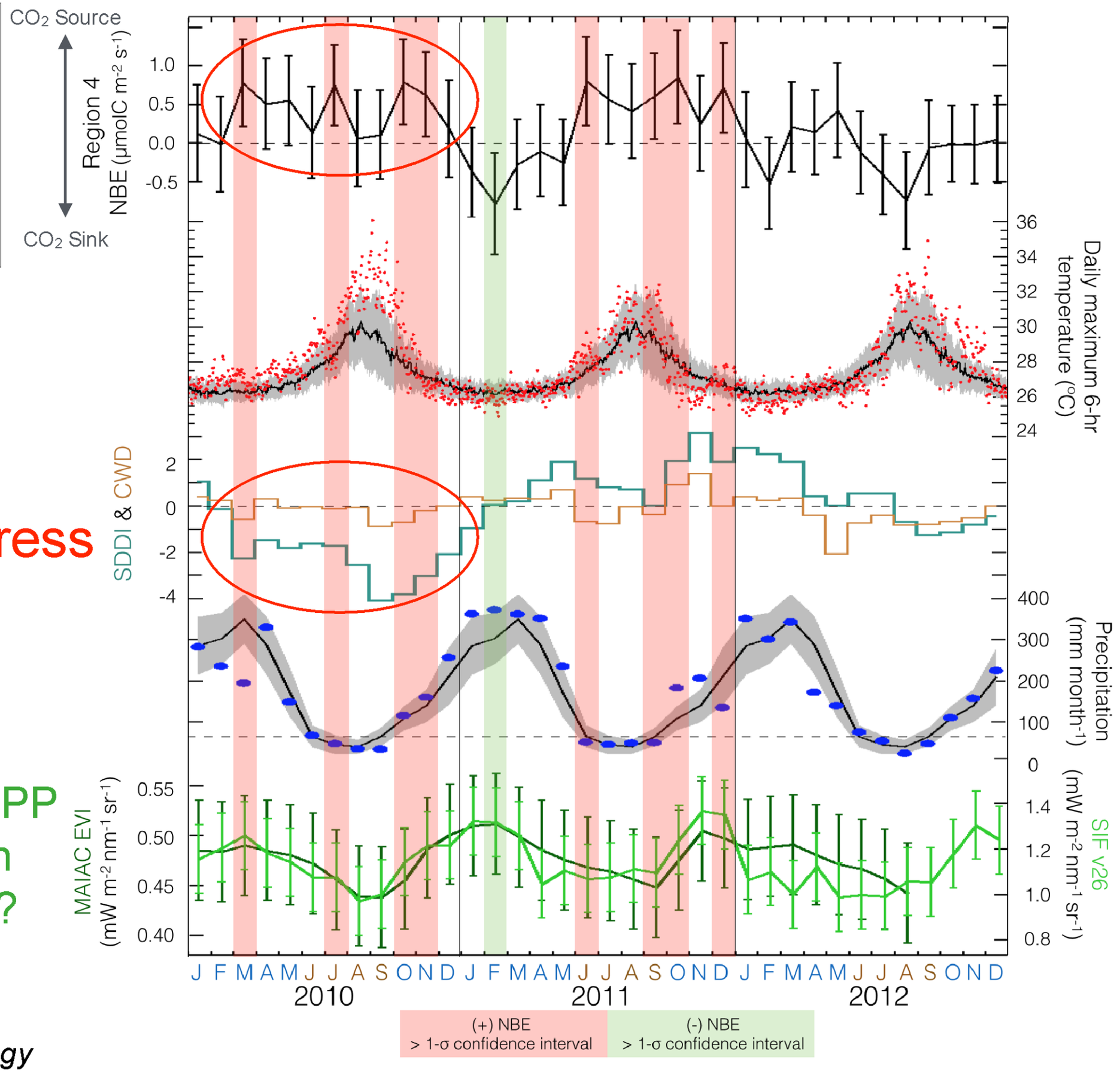
Alden et al.,
in review at *Global Change Biology*

Eastern Amazon monthly Net Biome Exchange



2010 Drought Stress

Evidence for lower GPP in 2010 dry season than in 2011, 2012?



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