AMAZONIAN ATMOSPHERIC CO₂ DATA SUGGEST MISSING MOISTURE SENSITIVITY IN CARBON-CLIMATE MODELS

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

- TRENODY models: 8 dynamic global vegetation models (DGVMs), S3 simulation driven by CRU-NCEP reanalysis
- Regional CO₂ inversion: 2010-2012 NBE, largely independent of prior flux estimates, Aircraft profiles in the Amazon = local CO₂ observations

Key questions:
Agreement in interannual / seasonal NBE?
Agreement in NBE sensitivity to moisture and temperature?
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
The inversion adjusts fluxes and background to minimize \([\text{Predicted} - \text{Observed CO}_2]\).

- 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

Less uptake

More uptake

Basin-wide NBE (Pg C yr⁻¹)

2010 NBE

Bottom-up

2011 NBE

2012 NBE

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

2010 - 2011

2010 - 2012
Regional NBE Seasonality: Central Amazon

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

Less uptake

More uptake
Regional NBE Seasonality: Central Amazon

- Top-down: larger differences in monthly NBE values from year to year
- TRENDY: consistent seasonality from year to year
- Wet / Dry season 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: $R = -0.79$

## Wet season Temperature Anomalies and NBE

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

<table>
<thead>
<tr>
<th>Temperature Anomalies</th>
<th>Inversion Flexpart</th>
<th>CLM</th>
<th>JULES</th>
<th>LPJ</th>
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<tbody>
<tr>
<td>C. Amazon wet season lag=0</td>
<td>0.89</td>
<td>0.80</td>
<td>0.88</td>
<td>0.52</td>
<td>0.90</td>
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<tr>
<td>E. Amazon wet season lag=0</td>
<td>0.66</td>
<td>0.40</td>
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<td>0.83</td>
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- Wet season temperature sensitivity well-represented by most models
# Wet season Precipitation Anomalies and NBE

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

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<td>-0.57</td>
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<td>E. Amazon wet season lag=1</td>
<td><strong>-0.79</strong></td>
<td>0.28</td>
<td>-0.09</td>
<td>0.16</td>
<td>0.14</td>
<td>-0.13</td>
<td>0.10</td>
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- 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 CO₂ inversion suggests
• TRENDY models agree with CO₂ 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

Inversion FLEX
CLM
JULES
LPJ
LPX
ORCHIDEE
OCN
VEGAS
VISIT

- 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

Wet season C uptake:
Resp. ↑ GPP ↑

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

2010 total resp.
2011 total resp.
2012 total resp.
2010 GPP
2011 GPP
2012 GPP

CO2 Flux (g C m⁻² day⁻¹)

Less uptake

More uptake
Regional NBE Seasonality: Eastern Amazon

- 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

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

- 2010 total resp.
- 2011 total resp.
- 2012 total resp.
- 2010 GPP
- 2011 GPP
- 2012 GPP

CO2 Flux (g C m⁻² day⁻¹)

2010 total resp.
2011 total resp.
2012 total resp.
2010 GPP
2011 GPP
2012 GPP

Less uptake

More uptake
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Uncertainty

Model-data Mismatch:
\[ R \text{ (ppm}^2\text{)} = \sigma^2 \text{ msmts} + \sigma^2 \text{ transport} + \sigma^2 \text{ background sampling} + \sigma^2 \text{ “other” fluxes} + \sigma^2 \text{ representation} \]

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

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)
\[ \sigma^2 \text{ prior flux} = (\text{ann mean monthly heterotrophic respiration from GFEDv3.1})^2 + (\text{std dev if differences btwn ann mean SiBCASA and CASA-GFED diurnal cycles})^2 \]

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

Background Uncertainty:
\[ \sigma \text{ Background} = (\text{std dev of historical differences between observations at ASC, RPB or FTL, according to latitude and altitude})^2 + (\text{std dev of differences between sampled CT2013_ei 4D field* and boundary curtain sampled at same latitude})^2 \]
*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

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FLEXPART

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HYSSPILT

Alden et al.,
in review at Global Change Biology
Patterns of flux variability very similar; magnitude different

Central Amazon

Eastern Amazon

Alden et al., in review at *Global Change Biology*
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
2010 Drought Stress

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

Alden et al., in review at Global Change Biology