CO$_2$ Flux Measurement
Uncertainty Estimates for the
NACP Site-Level Interim Synthesis

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Outline

• Background
• NEP \( (= -\int \text{NEE}) \)
  uncertainty associated with \( u_{Th} \) uncertainty
• NEP random uncertainty
• Summary
Purpose of this Talk

• Update community on progress (work in progress)
• Solicit feedback
Eddy-Covariance (EC) Measurement Uncertainties

Random uncertainty

- associated with random measurement noise
- can be characterized using:
  - similar periods on consecutive days
  - proximate paired towers
  - highly-tuned (gap-filling) model output
- NOT negligible at the annual time scale

Systematic uncertainty

- less well understood, less easily characterized
- caused by inadequate EC system design or violation of EC assumptions (as seen in, e.g., under-measurement at low windspeeds ($u^*$ or $\sigma_w$ filtering); energy balance non-closure; cold-air drainage or other 3D flow regimes)
Quantifying NEP Uncertainty Related to the Low-\(u_*\) NEE Exclusion Threshold \(u_*^{Th}\)
(adapted from Papale et al. 2006 with modifications)

- **Estimate** \(u_*^{Th}\) and its uncertainty using change-point detection
  - stratify each year into 4 seasons and each season into 3-7 temperature classes
  - plot binned NEE vs. \(u_*\) and evaluate the change-point for each stratum
  - aggregate all strata
  - Bootstrap 1,000 times per year
  - Pool estimates from all years
- **Fill gaps in NEE at all values of** \(u_*^{Th}\)
- **Estimate** NEP uncertainty as 95% confidence intervals from 2.5 and 97.5 percentiles
95% Confidence Intervals in the $u^{Th}_*$ in Relation to $u^{Th}_*$

Slope = 29%
$r^2 = 0.46$

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<table>
<thead>
<tr>
<th>Land Cover</th>
<th>Canada</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent Wetland (2)</td>
<td>CAMer CAWP1</td>
<td>USARM USIB1 USNe1,2,3</td>
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<tr>
<td>Cropland (5)</td>
<td></td>
<td>USIB2 USShd USVar</td>
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<tr>
<td>Shrubland/Savanna (3)</td>
<td></td>
<td>USLos USSO2 USTon</td>
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<td>Grassland (4)</td>
<td>CALet</td>
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<tr>
<td>Juvenile Forest (6)</td>
<td>CACa2,3 CASJ1,2</td>
<td>USMe3,5</td>
</tr>
<tr>
<td>Mature Evergreen Needleleaf Forest (12)</td>
<td>CACa1 CANS1 CAObs CAOjp CAQfo CASJ3 CATP4</td>
<td>USDk3 USHo1 USMe2,4 USNR1</td>
</tr>
<tr>
<td>Mature Deciduous Broadleaf Forest (6)</td>
<td>CAOas</td>
<td>USHa1 USMMS USMoz USUMB USWCr</td>
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<tr>
<td>Mature Mixedwood Forest (4)</td>
<td>CAGro</td>
<td>USDk2 USPFa USSyv</td>
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<tr>
<td>Land Cover</td>
<td>Mean $\pm$ S.D. (n)</td>
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<tr>
<td>Permanent Wetland</td>
<td>$0.12 \pm 0.00$ (2)</td>
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<tr>
<td>Cropland</td>
<td>$0.19 \pm 0.06$ (5)</td>
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<tr>
<td>Shrubland &amp; Savanna</td>
<td>$0.20 \pm 0.05$ (3)</td>
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<tr>
<td>Grassland</td>
<td>$0.21 \pm 0.05$ (5)</td>
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<tr>
<td>Juvenile Forest</td>
<td>$0.20 \pm 0.07$ (6)</td>
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<tr>
<td>Mature Evergreen Needleleaf Forest</td>
<td>$0.38 \pm 0.13$ (11)</td>
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<tr>
<td>Mature Deciduous Broadleaf Forest</td>
<td>$0.40 \pm 0.07$ (6)</td>
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</tr>
<tr>
<td>Mature Mixedwood Forest</td>
<td>$0.41 \pm 0.07$ (3)</td>
<td></td>
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</tbody>
</table>
Percentage of Nighttime Net Ecosystem Exchange NEE Data Excluded by the Median $u_{*}^{Th}$

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$u^{Th}_*$-Related Uncertainty in Annual NEP
(95% Confidence Interval, g C m$^{-2}$)
in Relation to Annual NEP

Needleleaf Forest
Broadleaf Forest
Mixedwood Forest
Juvenile Forest
Wetland
Grassland
Shrubland
Cropland

Canada: 13 ± 9
USA: 22 ± 18
Quantifying Random Uncertainty
(annual analysis following Richardson et al. 2006, 2007)

- Quantify NEE random uncertainty curve
- Apply Monte-Carlo process
  - Begin with gap-free synthetic data from Fluxnet-Canada gap-filling model
  - Add random noise
  - Fill gaps
  - Repeat 1,000 times
  - Calculate uncertainty at different time scales as 95% confidence intervals from 2.5 and 97.5 percentiles

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Random Uncertainty in NEE

(showing $\mu$ ($\mu$mol m$^{-2}$ s$^{-1}$) from a double exponential distribution in relation to gap-filling NEEHat)
Random Uncertainty in Annual NEP
(95% Confidence Interval, g C m\(^{-2}\))
in Relation to Annual NEP

Needleleaf Forest
Broadleaf Forest
Mixedwood Forest
Juvenile Forest
Wetland
Grassland
Shrubland
Cropland

Ameriflux 2009
Random Uncertainty in Annual NEP
(95% Confidence Interval, g C m\(^{-2}\))
in Relation to Ecosystem Respiration RE

- Needleleaf Forest
- Broadleaf Forest
- Mixedwood Forest
- Juvenile Forest
- Wetland
- Grassland
- Shrubland
- Cropland

Slope = 3.6%
\(r^2 = 0.23\)

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Random Uncertainty in Annual NEP
(95% Confidence Interval, \( g \ C \ m^{-2} \))
in Relation to Annual RE: Forest Sites

\[
\text{Slope} = 3.5\%
\quad r^2 = 0.23
\]

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Random Uncertainty in Annual NEP (95% Confidence Interval, g C m\(^{-2}\)) in Relation to Annual RE: Non-Forest Sites

\[ \text{Slope} = 4.5\% \]
\[ r^2 = 0.15 \]
Why Inter-Site Differences?
Two possibilities to explore:

1. It’s in the data.
   - Differences in system design or data processing?
   - Differences in site characteristics?

2. It’s in the processing.
   - Poor performance of Fluxnet-Canada gap-filling method at some sites causing overestimation of random errors.
Summary

• $u_{*}^{Th}$ is well defined at most sites.
• Mean nighttime NEE exclusion of 59%.
• Overall NEP uncertainties (g C m$^{-2}$ yr$^{-1}$, mean ± s.d.):
  – random: 30 ± 16
  – $u_{*}^{Th}$ - related: 18 ± 16
• Both uncertainties scale with RE but some sites have higher uncertainties than others.

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Next Steps …

• Explore differences among sites.
• Repeat random uncertainty analysis with other gap-filling methods.
• Get feedback from site PIs, identify problems and weaknesses, complete a second analysis at some sites.
• Extend $u^*_{Th}$ analysis to entire FLUXNET database.