The Year of the "Locust":
Net Ecosystem Production during an Emergence of Periodical Cicada

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Site: MMSF AmeriFlux Tower

- Morgan-Monroe State Forest (MMSF), Indiana
- mixed deciduous (oak, maple, hickory,...), ~ 90 yrs
**Eddy-Covariance: Closed Path System**

**AmeriFlux Tower: Instrumentation**

\[ w'c' = \text{cov}(w_t,c_t) \]

Lagged E-C: \( \text{cov}(w_t,c_{t-\tau}) \)

- \( \tau \): determined so that covariance is maximized

Fluxes are determined in post-processing of 10 Hz data-stream (> 1GByte/week)
Hourly Fluxes of CO$_2$ over 8 Years (MMSF)

NEE: *Net Ecosystem Exchange* = Respiration - Assimilation
Hourly Fluxes of CO$_2$ over 8 Years (MMSF)

Measurement Uncertainty?

- **random uncertainty** (instruments, gap-filling)
- **systematic bias** (instruments, gap-filling)
- **turbulence uncertainty** (stochasticity of process)

**Random Instrument Uncertainty**

**Model Uncertainty (Gap-Filling)**

Dragonì et al. (JGR, 2007)
Hourly Fluxes of CO₂ over 8 Years (MMSF)

Role of Measurement Gaps and Gap-Fill Model in Annual Sums

<table>
<thead>
<tr>
<th>Year</th>
<th>NEP gC m⁻² y⁻¹</th>
<th>σ(NEP) (%)</th>
<th>rNEPₘ (%)</th>
<th>Gaps (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>-367</td>
<td>3</td>
<td>82</td>
<td>50</td>
</tr>
<tr>
<td>2000</td>
<td>-267</td>
<td>4</td>
<td>80</td>
<td>56</td>
</tr>
<tr>
<td>2001</td>
<td>-304</td>
<td>3</td>
<td>70</td>
<td>42</td>
</tr>
<tr>
<td>2002</td>
<td>-366</td>
<td>3</td>
<td>63</td>
<td>38</td>
</tr>
<tr>
<td>2003</td>
<td>-274</td>
<td>4</td>
<td>67</td>
<td>43</td>
</tr>
<tr>
<td>2004</td>
<td>-418</td>
<td>3</td>
<td>71</td>
<td>38</td>
</tr>
<tr>
<td>2005</td>
<td>-386</td>
<td>3</td>
<td>60</td>
<td>36</td>
</tr>
<tr>
<td>2006</td>
<td>-360</td>
<td>3</td>
<td>62</td>
<td>38</td>
</tr>
</tbody>
</table>

Gaps: ~ 35 – 55%
- ~ 60-80% of total uncertainty
- mostly nighttime
- strict quality control (data rejection)

Overall random uncertainty on annual sums is relatively small

Dragoni et al. (JGR, 2007)
Cumulative Exchange of CO₂ over 9 Years (MMSF)

NEE: *Net Ecosystem Exchange* = Respiration - Assimilation

\[
30 \text{ tons C ha}^{-1} = 3 \text{ kg C m}^{-2}
\]
Annual Net Ecosystem Production (NEP)

- all data re-analyzed (consistent methods)
- (random) uncertainty estimate by Monte-Carlo method

1999-2003:
\[ \mu_{\text{NEE}} \approx 316 \, \text{g(C)m}^{-2}\text{a}^{-1} \]
\[ \sigma_{\text{NEE}} \approx 44 \, \text{g(C)m}^{-2}\text{a}^{-1} \]
-NEP = NEE = RE - GEP

• 2004 NEE “pulse” is due to GEP, not RE
• 2004/2005 are “normal”
Comparison with Biometric NEP Estimates

- no 2004/2005 “pulse” in biometry estimates

✅ biometry estimates based on above ground!
Were 2004 & 2005 Climatically Unusual?

- 2004 & 2005 do not stand out climatically
- (2004 rather low in PAR, average $T_{air}$)
- NEE “pulse” is not due to climatic forcing
Unusual Physiology Indices in 2004/2005?

LUE = GEP/PPFD [mol mol⁻¹]  WUE = GEP/E [mmol mol⁻¹]

2004: ≈ 2.2%
1999-2003: ≈ 1.7%

1999-2003: ≈ 3.3
2004: ≈ 4.3

• 2004 & 2005 do stand out physiologically
• higher water use, and light use efficiencies
What can cause these Effects?

... 2004 was the Year of the Brood X Cicada

17 year periodical cicada: next emergence in 2021
Periodical Cicada

- 17 years or 13 years
- Brood X (17 yr) is largest
- IN, IL, OH, KY; centered on southern Indiana
- other branch in DC area

- root xylem feeders
- no feeding after emergence
- emergence within a few days
- mate and die in ~ 2-3 weeks
- oviposition in tree-branches
- young nymphs fall off and enter soil after a few days
- nymphs grow over 17 years
• up to 200 emergence “chimneys” per square meter
• “chimneys” about 15 cm
• mature nymphs metamorphise into adults
Can a Cicada Emergence Cause a Pulse in NEE?

Red Maple Growth Increments. Shakamack State Forest, 13-year brood. Data from Jim Speer, ISU

but evidence is not consistent:
• no pulse in other tree species
• no dendrometer pulse (yet)

• Allocation pulse below ground?
Cicada Enhanced Mechanisms for C-Allocation?

- Cicada as “Ecosystem Engineers”?

Emergence “chimneys” enhance aeration of root system

⇒ Literature (Yordanova et al. 2003): insect “chimneys” provide relief from root anoxia and associated drop in Rubisco and photorespiratory enzyme activity
Pulse in Nitrogen Availability?

MMSF average emergence density:
- $\sim 20 \text{ cic. m}^{-1} = 200,000 \text{ cic. ha}^{-1}$ ($\approx \frac{1}{2} \text{ Million per acre}$)
- $\approx 200 \text{ kg cicada ha}^{-1}$

- with $\sim 0.02$-$0.03 \text{ g N per cic.}$: $4$-$6 \text{ kg N ha}^{-1}$

- with $\sim 3.74 \% \text{ N in cicada mass}$: $\sim 7.5 \text{ kg N ha}^{-1}$
  - “loss” due to foraging $\sim 70\%$? Immobilized how long?

- total atm. N-flux to forest (MMSF): $14$-$19 \text{ kg N ha}^{-1} \text{ a}^{-1}$
- internal N-cycling (MMSF): $140$-$150 \text{ kg N ha}^{-1} \text{ a}^{-1}$
  - (mineralization, litterfall)

Cicada N-pulse: $\approx 5\%$ of ann. N-cycling, released in 21 d
Does a 5% N-pulse have an effect on trees?

Cicada Enhanced Mechanisms for C-Allocation?

- study at Indiana University (Keith Clay) found massive mycorrhizal colonization on tree roots post emergence

⇒ boost in (e.g.)N-fixation can lead to enhanced photosynthesis (LUE, WUE)

Potential cause:
Many below-ground insects excrete antifungal substance as protection from fungal pathogens.

*Do cicada larvae inhibit growth of mycorrhizal fungi?*
Response of Ecosystem to Stress Pulse: (from Lambers et al. 1998)
**Conclusions**

- Periodical Cicada have large areal coverage in eastern United States
- Cicada induced pulse in NEE is potentially a large-scale phenomenon
- Large scale implications on terrestrial carbon budget
- Detected by micrometeorological methods: spatial aggregate sampling of eddy-covariance
Princeton University, 1970 Commencement

- Bob Dylan receives honorary degree
- ceremony outside, during Brood-X cicada emergence of “biblical dimensions”
- Commemorated in song *Day of Locusts* (on *New Morning*, 1970)

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*Day of Locusts*

...  
I put down my robe, picked up my diploma,  
Took hold of my sweetheart and away we did drive,  
Straight for the hills, the black hills of Dakota,  
Sure was glad to get out of there alive.  
And the locusts sang, well, it give me a chill,  
Yeah, the locusts sang such a sweet melody.  
And the locusts sang with a high whinin’ trill,  
Yeah, the locusts sang and they was singing for me,  
Singing for me, well, singing for me.

Bob Dylan
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