

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

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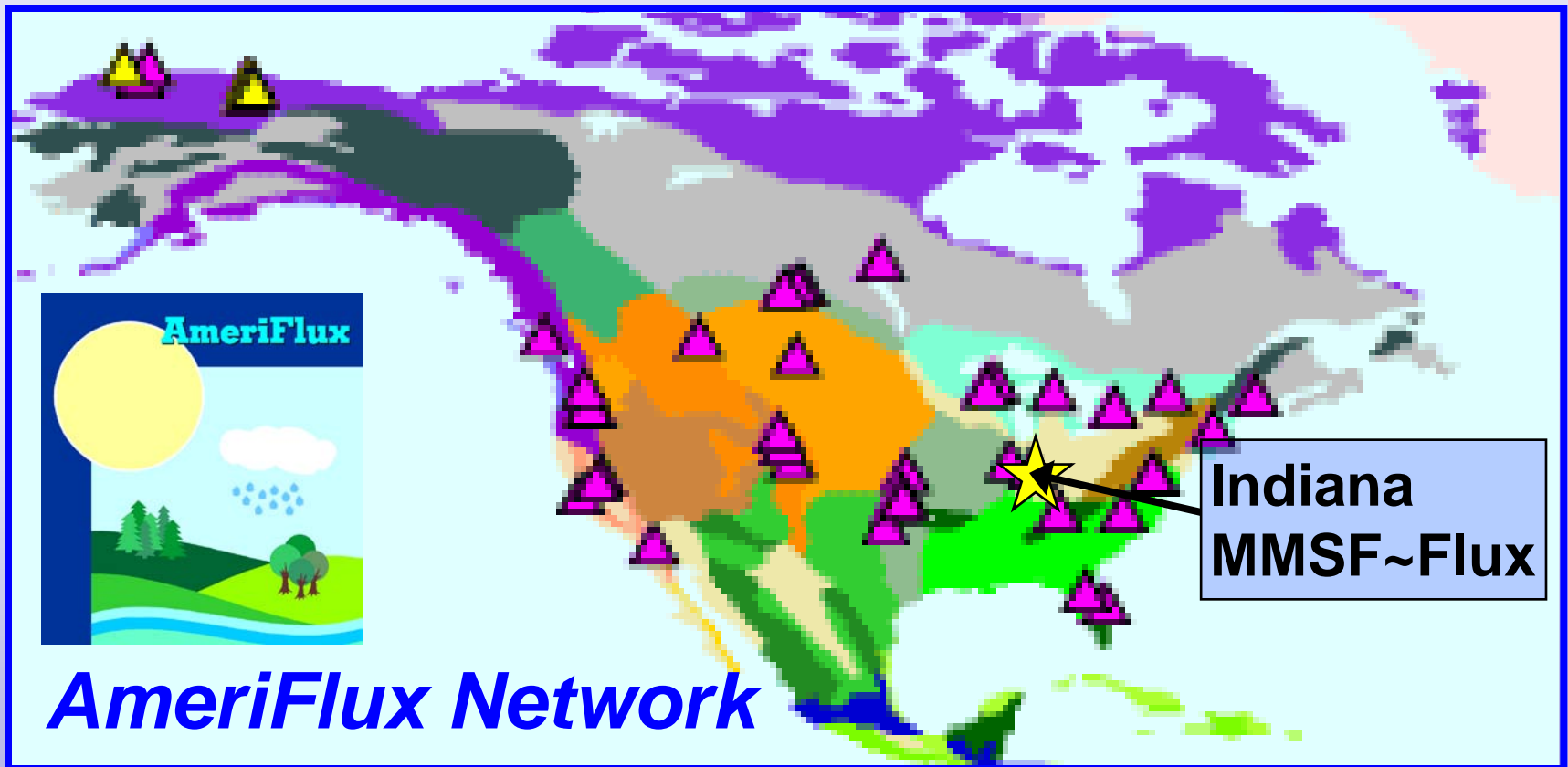
Danilo Dragoni, Craig Wayson, *Indiana University*

Sue Grimmond, *Kings College London and Indiana University*



Site: **MMSF AmeriFlux Tower**

- Morgan-Monroe State Forest (MMSF), Indiana
- mixed deciduous (oak, maple, hickory,...), ~ 90 yrs

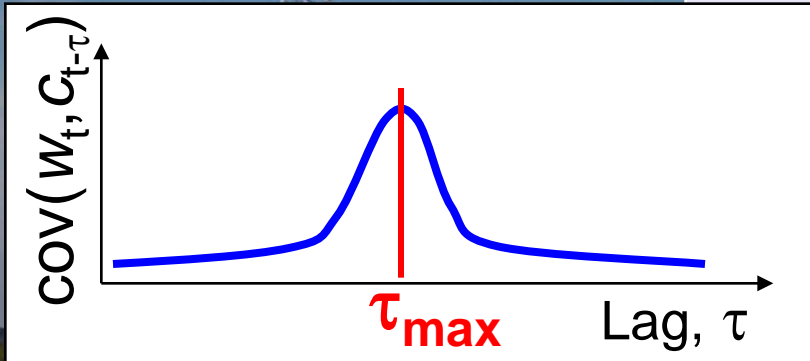


Eddy-Covariance: Closed Path System

AmeriFlux Tower: Instrumentation
 Eddy-Covariance: $w'c' = \text{cov}(w_t, c_t)$

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

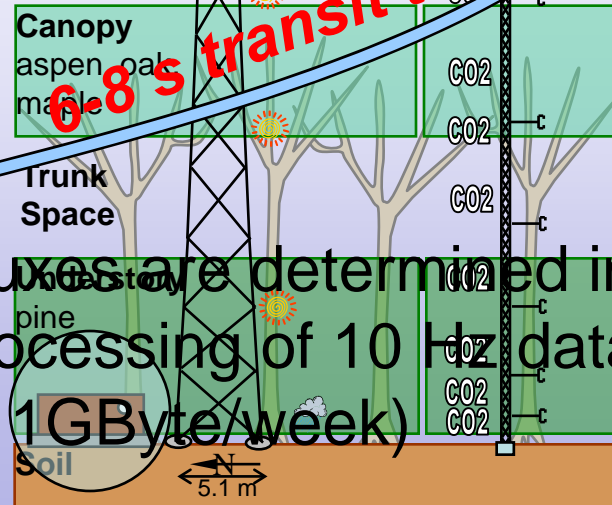
- τ : determined so that covariance is maximized



Height (feet & meters)

150
45.7

130
39.6

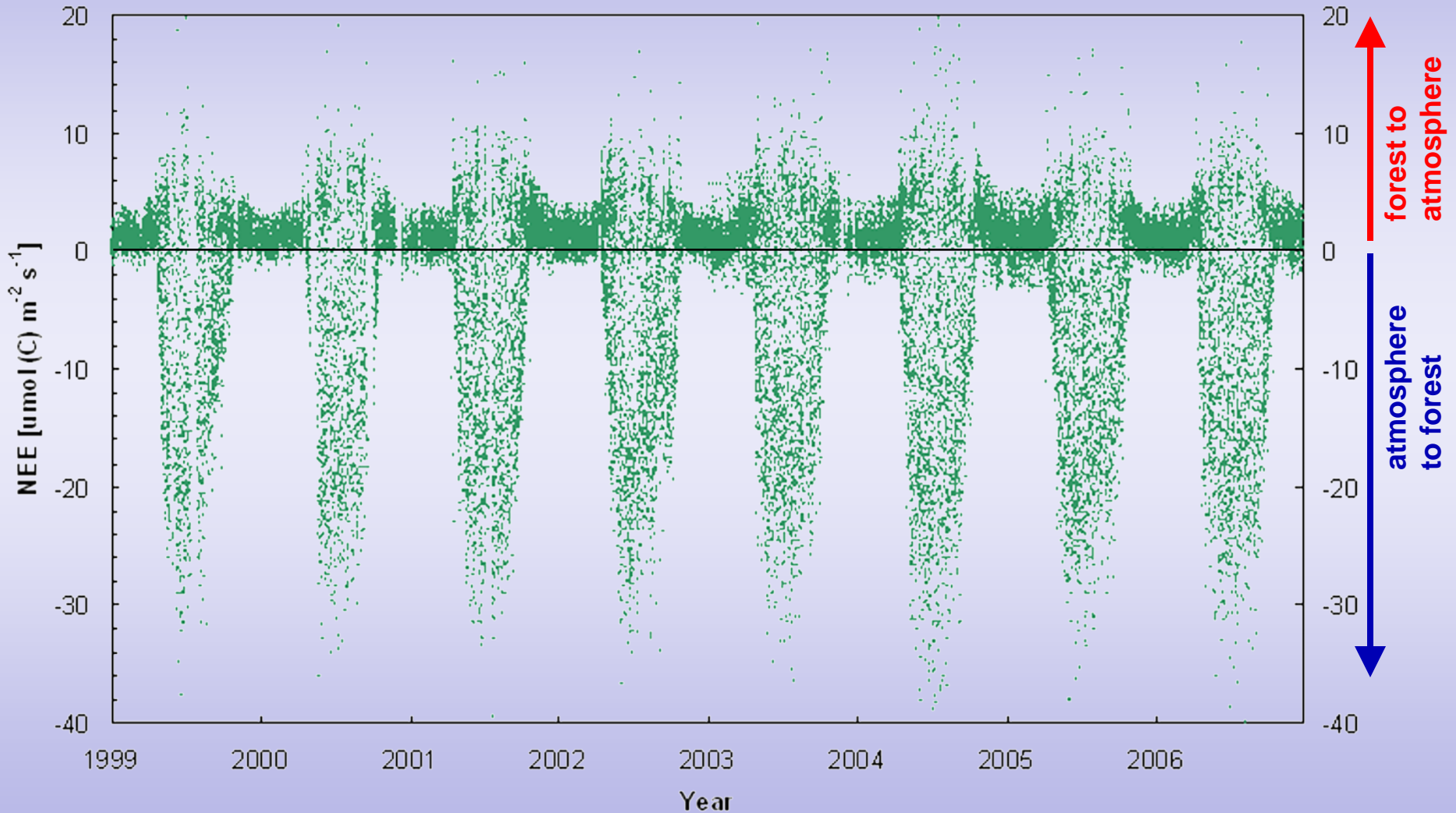


Fluxes are determined in post-processing of 10 Hz data-stream (> 1GByte/week)



Hourly Fluxes of CO₂ over 8 Years (MMSF)

NEE: *Net Ecosystem Exchange* = Respiration - Assimilation

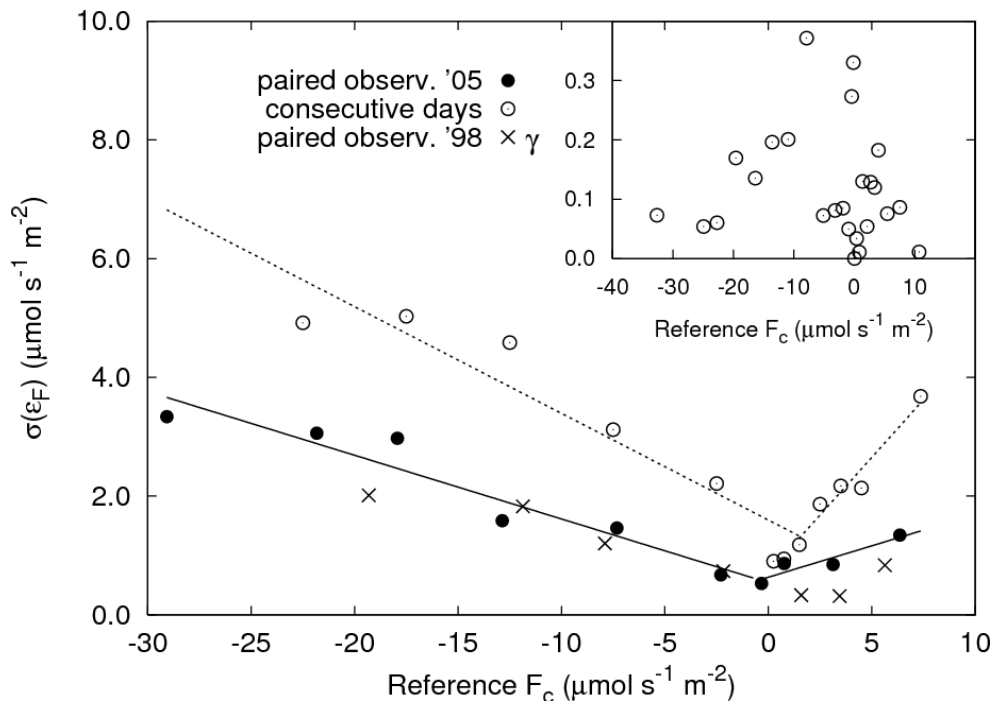


Hourly Fluxes of CO₂ over 8 Years (MMSF)

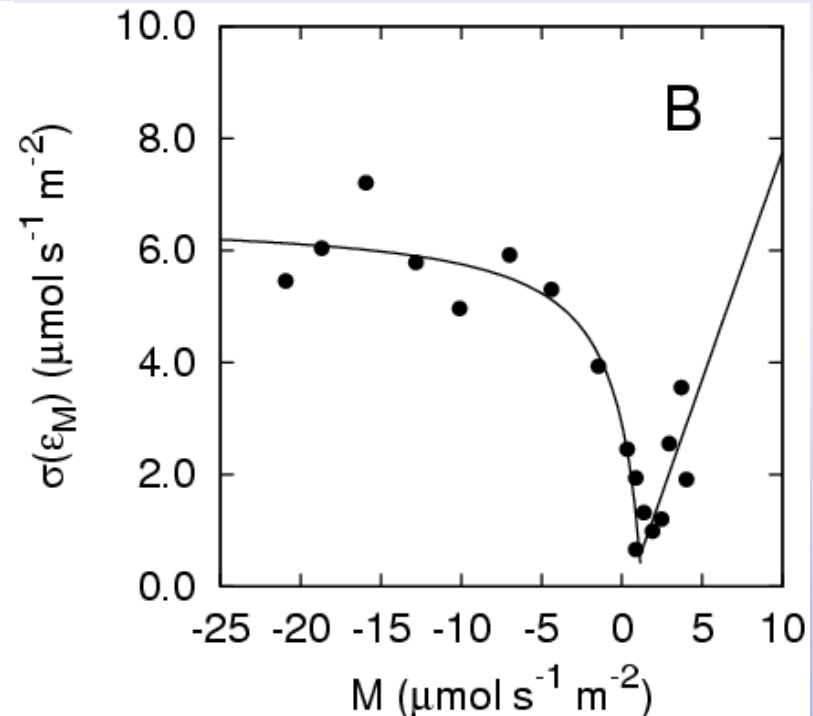
Measurement Uncertainty?

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

Random Instrument Uncertainty

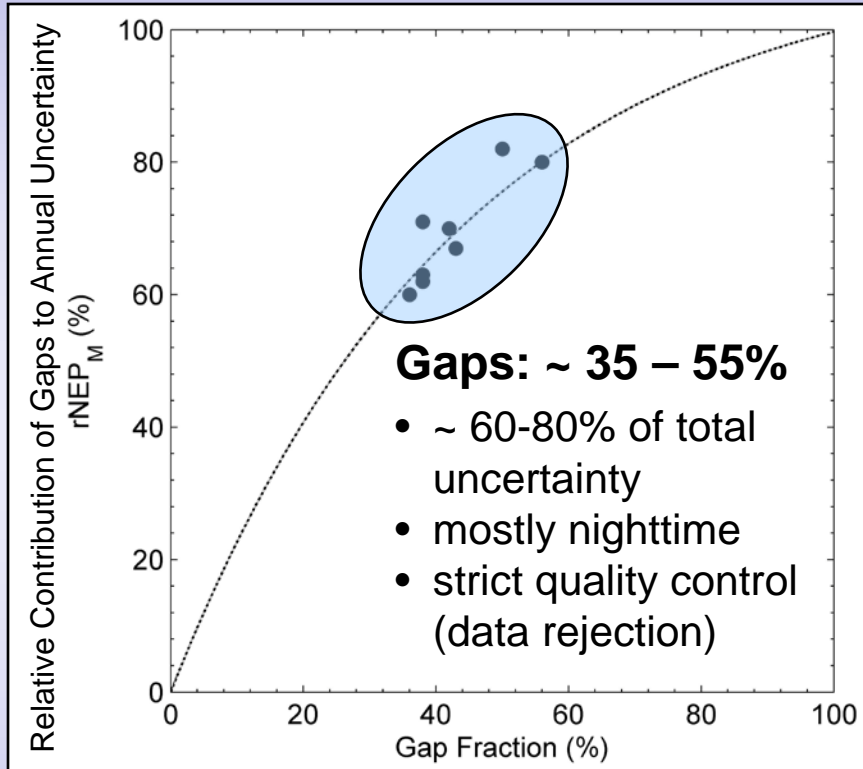


Model Uncertainty (Gap-Filling)



Hourly Fluxes of CO₂ over 8 Years (MMSF)

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



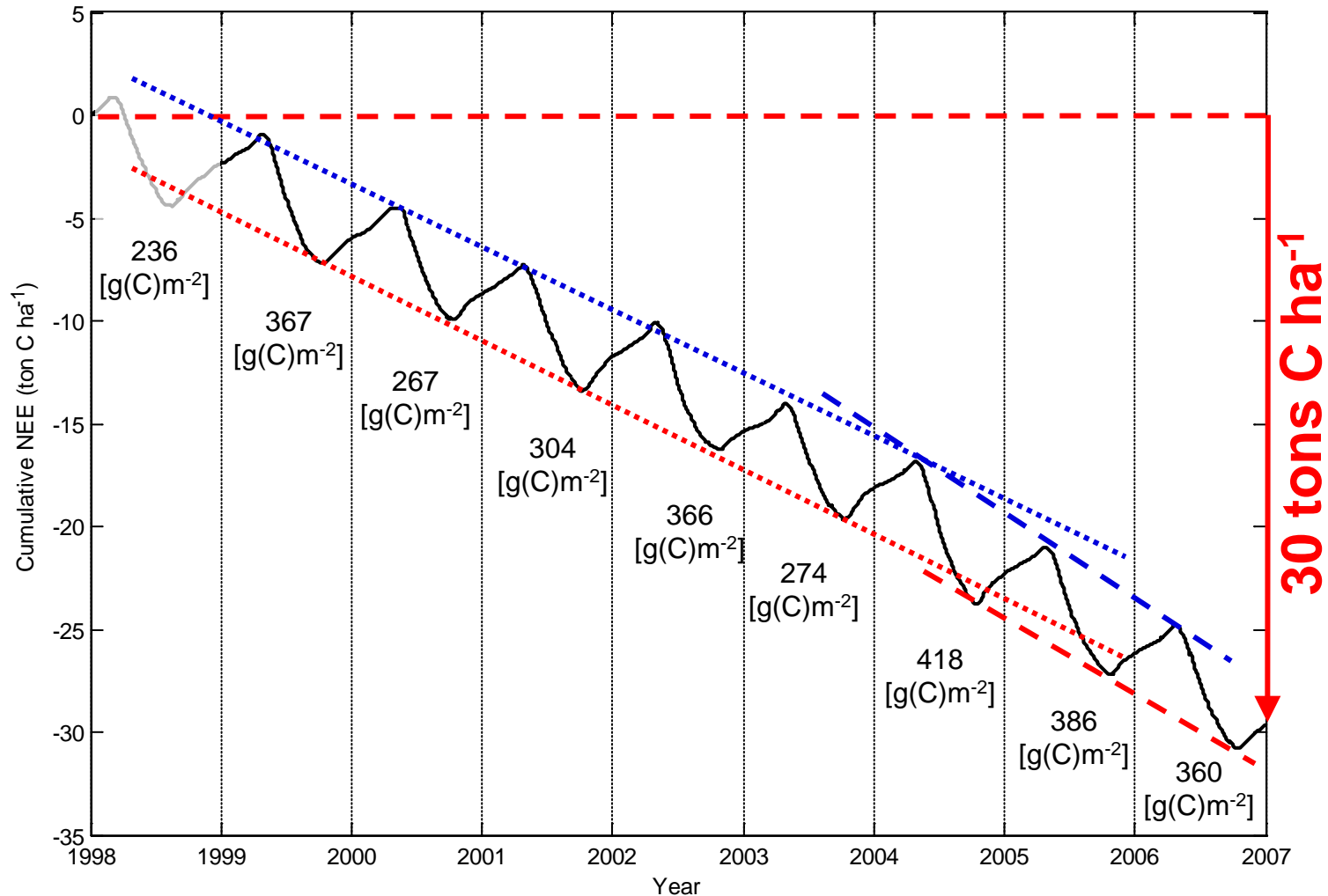
Year	NEP gC m ⁻² y ⁻¹	$\sigma(\text{NEP})$ (%)	$r\text{NEP}_M$ (%)	Gaps (%)
1999	-367	3	82	50
2000	-267	4	80	56
2001	-304	3	70	42
2002	-366	3	63	38
2003	-274	4	67	43
2004	-418	3	71	38
2005	-386	3	60	36
2006	-360	3	62	38

Dragoni *et al.* (JGR, 2007)

overall *random* uncertainty on annual sums is relatively small

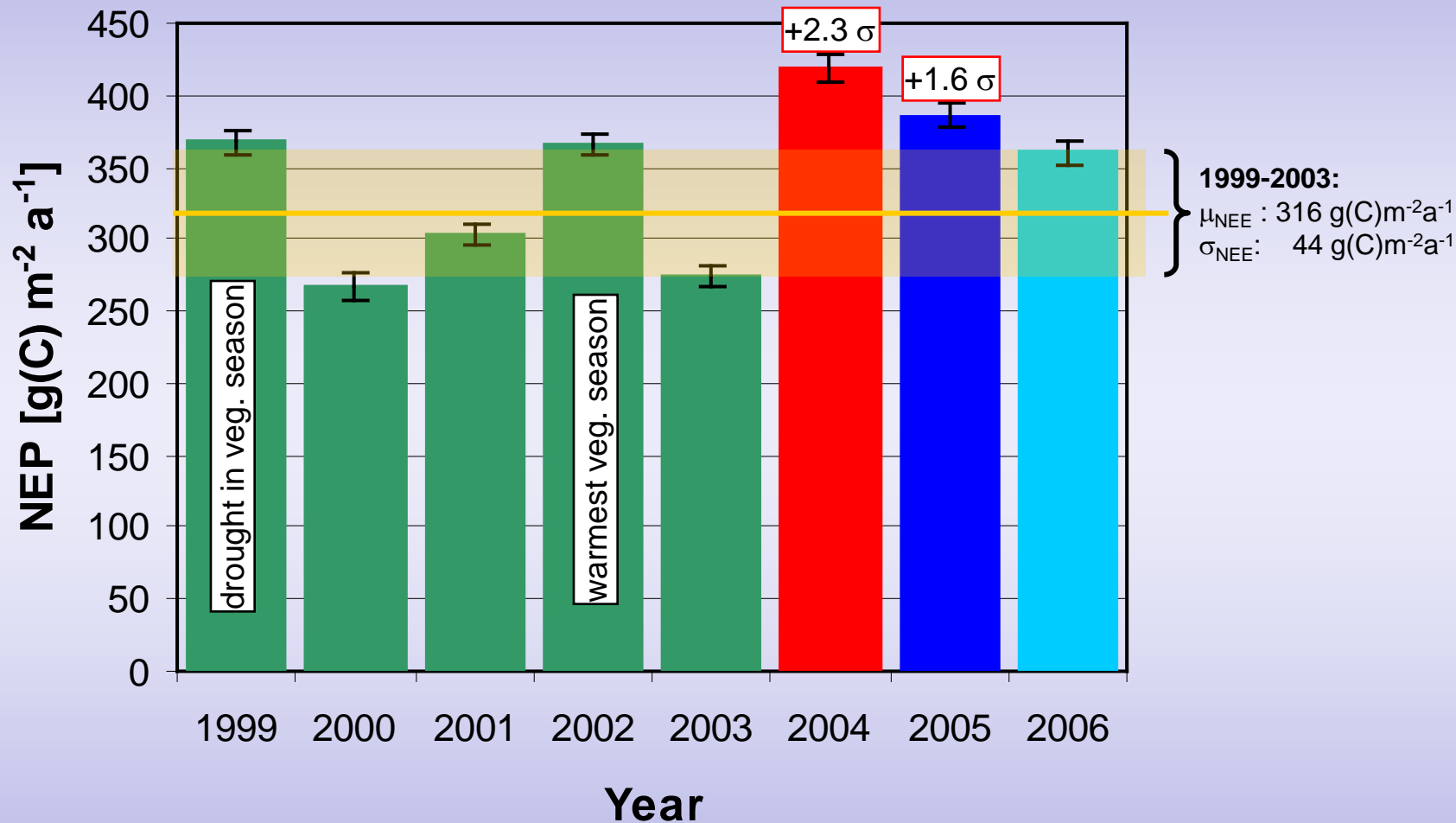
Cumulative Exchange of CO₂ over 9 Years (MMSF)

NEE: *Net Ecosystem Exchange* = Respiration - Assimilation



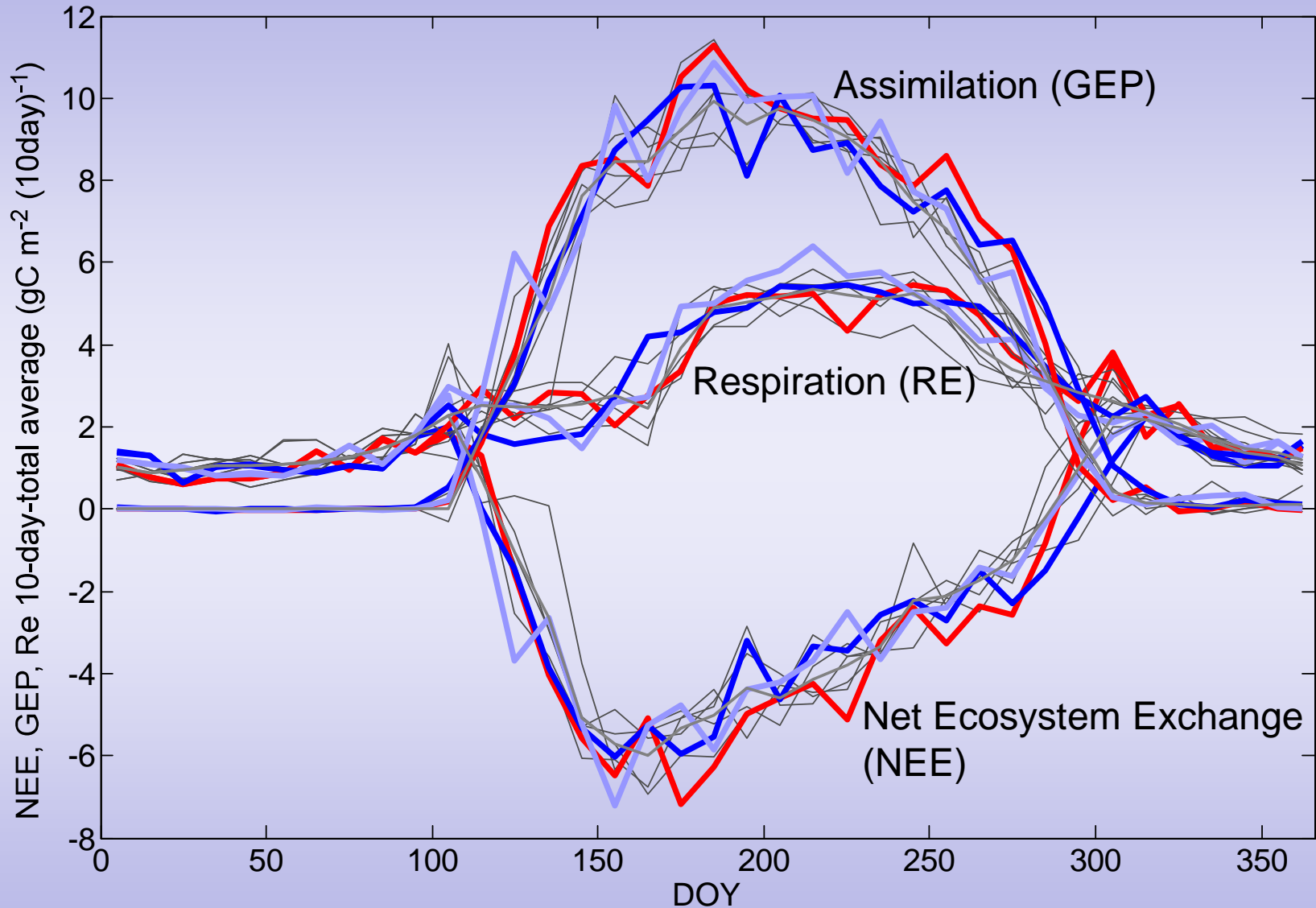
30 tons C ha⁻¹ = 3 kg C m⁻²

Annual Net Ecosystem Production (NEP)



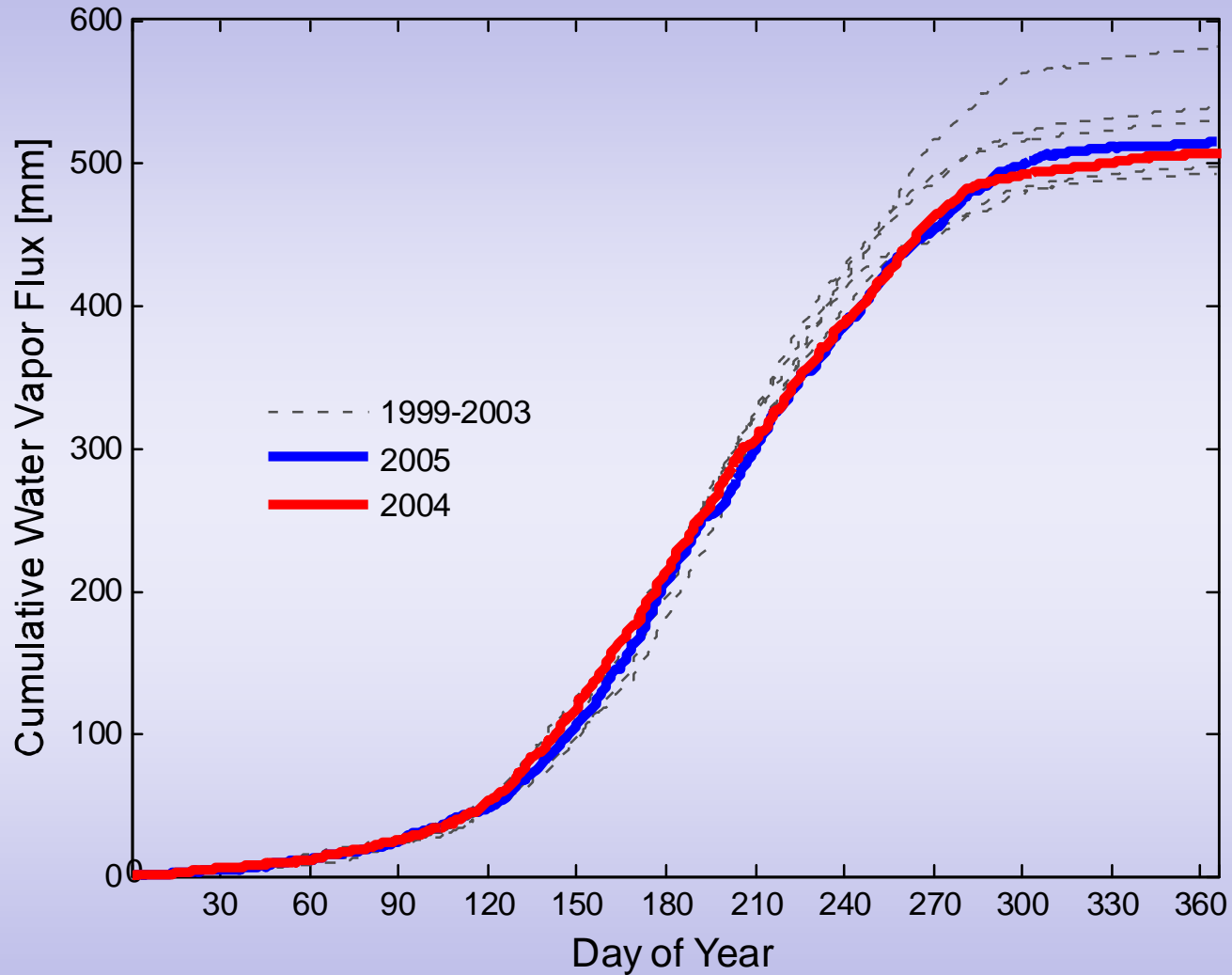
- all data re-analyzed (consistent methods)
- (random) uncertainty estimate by Monte-Carlo method

$$-NEP = NEE = RE - GEP$$



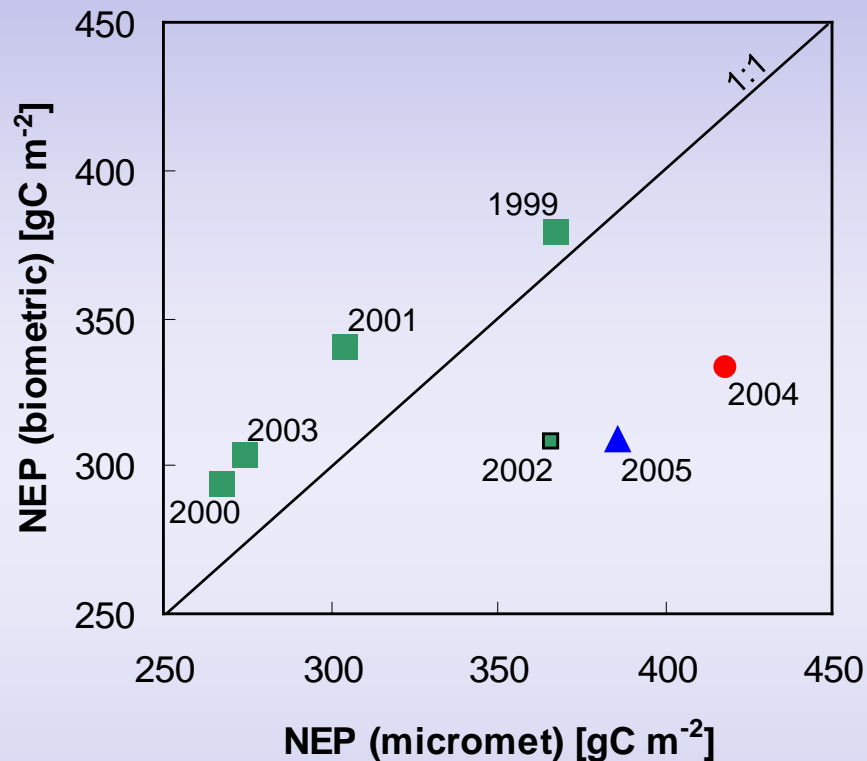
- 2004 NEE “pulse” is due to GEP, not RE

Water Vapor Flux



- **2004/2005 are “normal”**

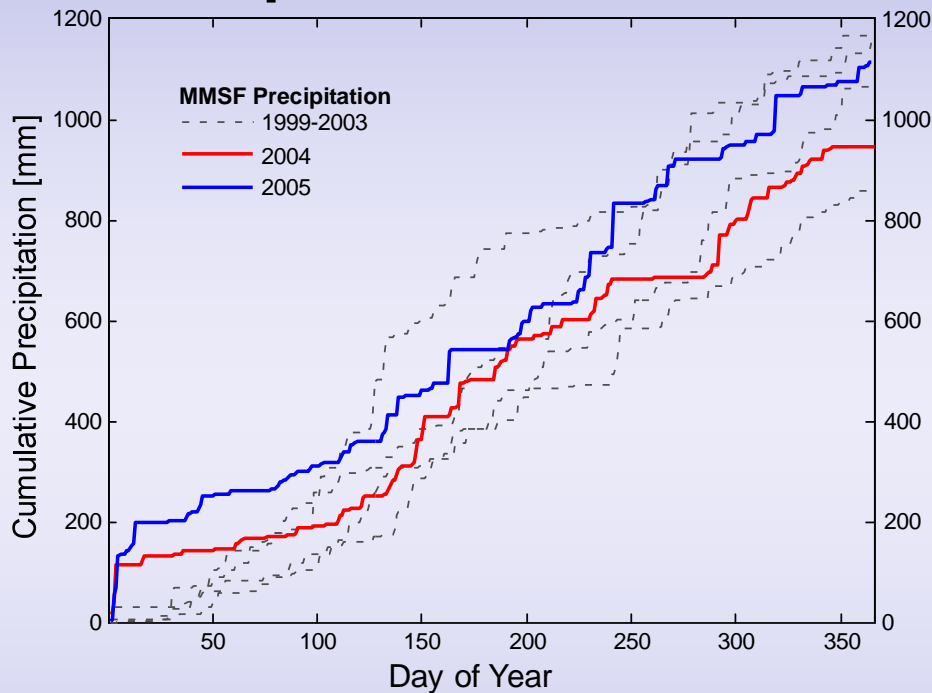
Comparison with Biometric NEP Estimates



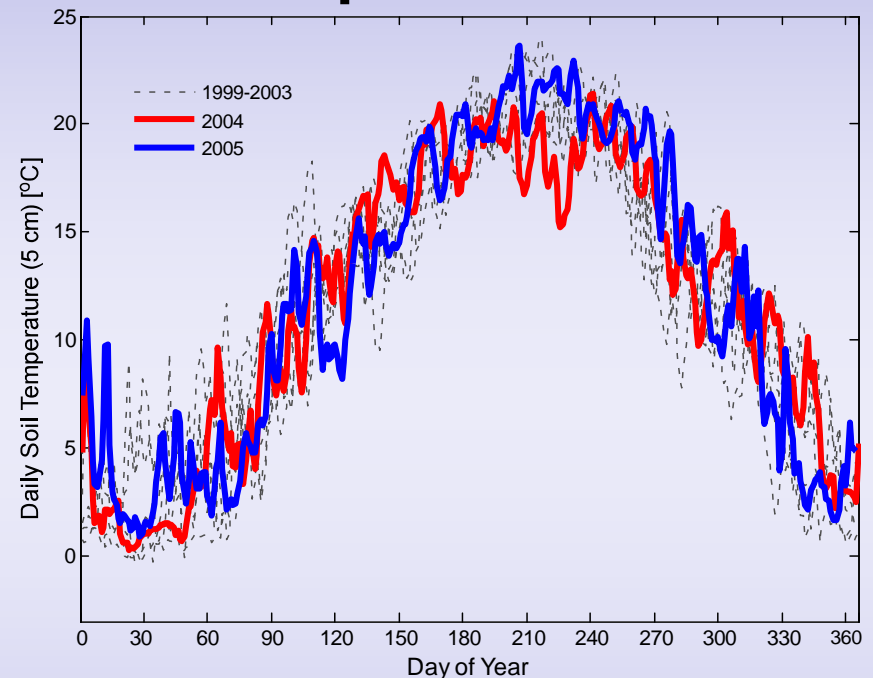
- E-C & biometry ~ match for 1999-2003 (2002?)
- no 2004/2005 “pulse” in biometry estimates
- ☑ **biometry** estimates based on **above ground!**

Were 2004 & 2005 Climatically Unusual?

Precipitation



Soil Temperature

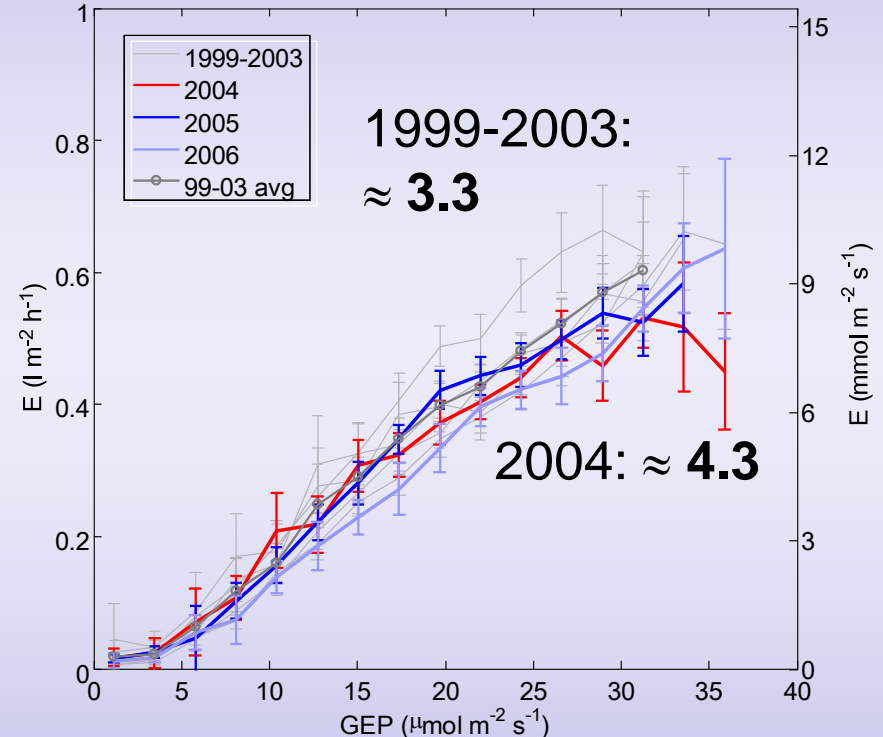
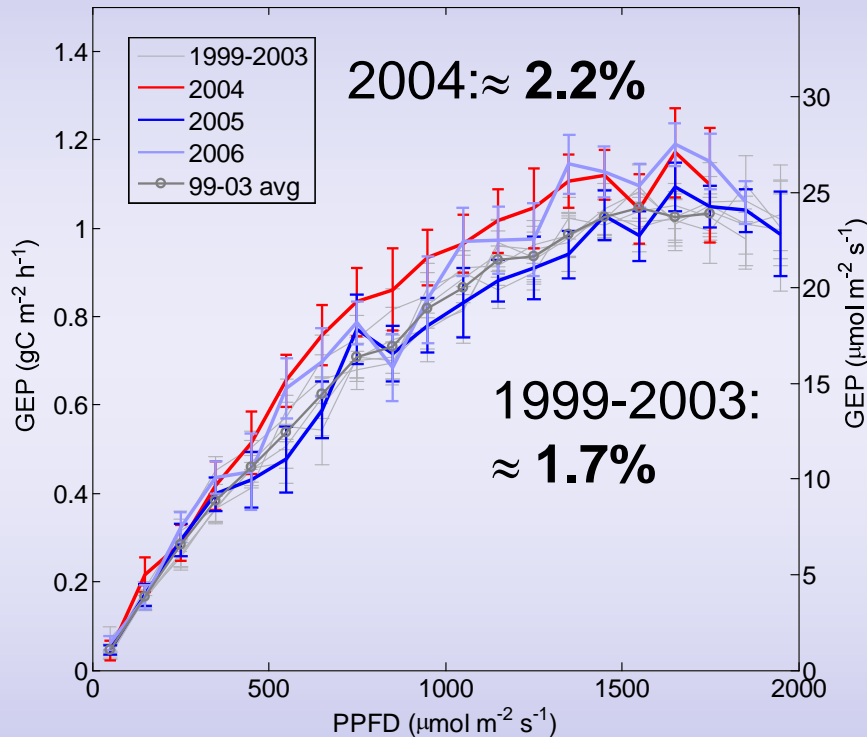


- 2004 & 2005 do not stand out **climatically**
- (2004 rather low in PAR, average T_{air})
- NEE “pulse” is not due to climatic forcing

Unusual Physiology Indices in 2004/2005?

LUE = GEP/PPFD [mol mol^{-1}]

WUE = GEP/E [mmol mol^{-1}]



- 2004 & 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



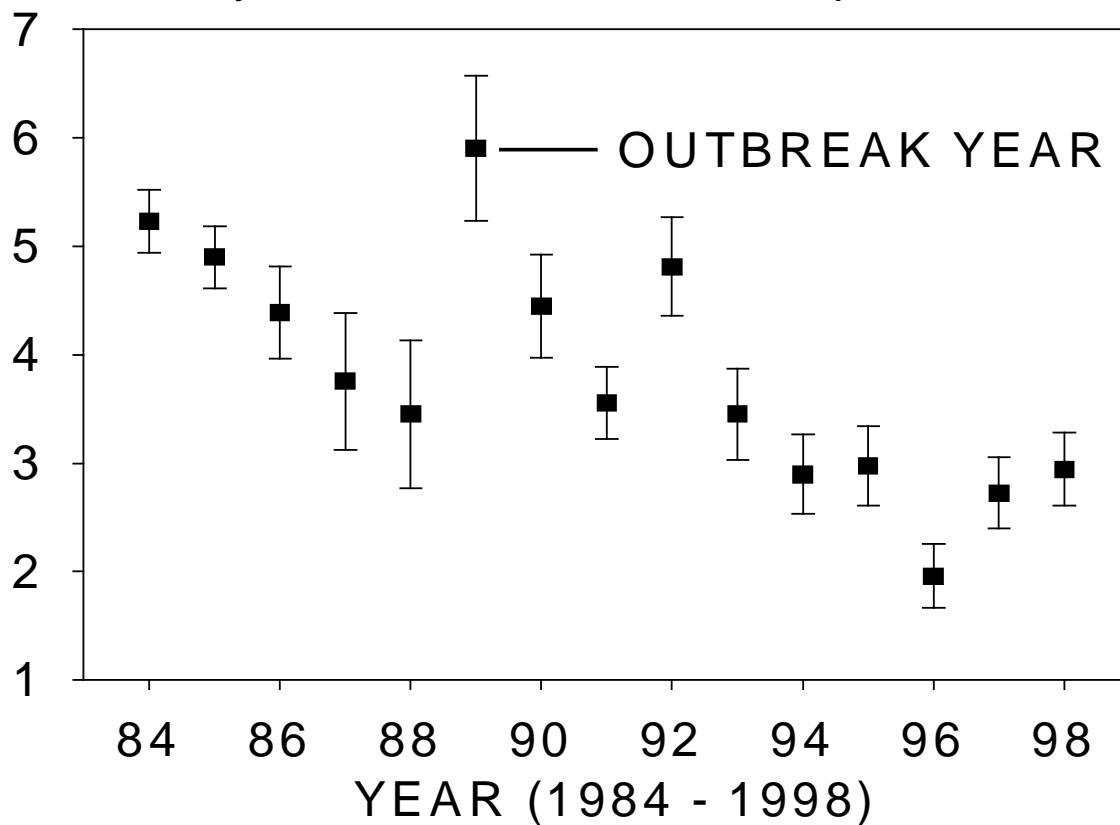
- up to 200 emergence “chimneys” per square meter
- “chimneys” about 15 cm
- mature nymphs metamorphise into adults





Can a Cicada Emergence Cause a Pulse in NEE?

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



(photo © H.D. Grissino-Mayer)

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:

- ~ 20 cic. $m^{-1} = 200,000$ cic. ha^{-1} ($\approx \frac{1}{2}$ Million per acre)
- ≈ 200 kg cicada ha^{-1}

Based on **Whiles *et al.*** (2001, *Am. Midl. Nat.* 145: 176-187):

- with ~ 0.02 - 0.03 g N per cic.: **4-6 kg N ha^{-1}**

Based on **Yang** (2004, *Science* 306: 1565-1567):

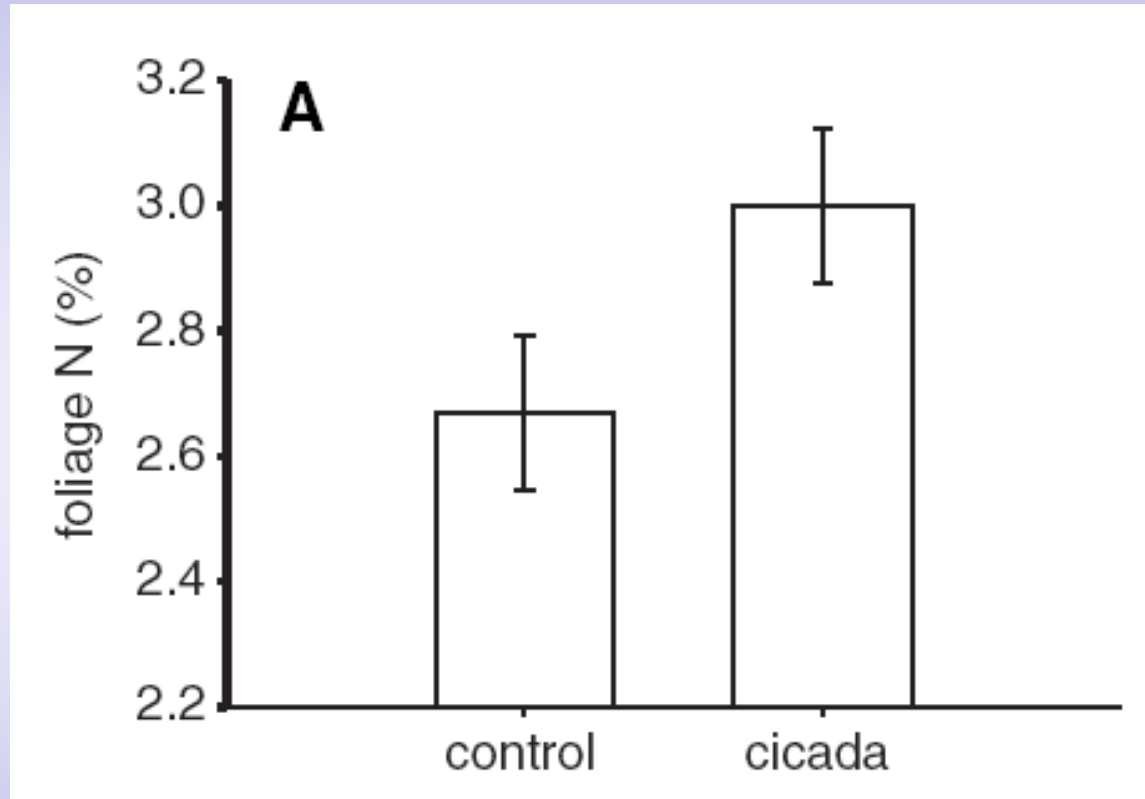
- with ~ 3.74 % N in cicada mass: **~ 7.5 kg N ha^{-1}**
“loss” due to foraging $\sim 70\%$? Immobilized how long?

Pryor & Barthelmie (2005, *Wat. Air Soil Poll.* 163: 203-227):

- total atm. N-flux to forest (MMSF): **14-19 kg N ha^{-1} a^{-1}**
- internal N-cycling (MMSF): **140-150 kg N ha^{-1} 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?



Yang (2004, *Science* 306: 1565-1567)

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.

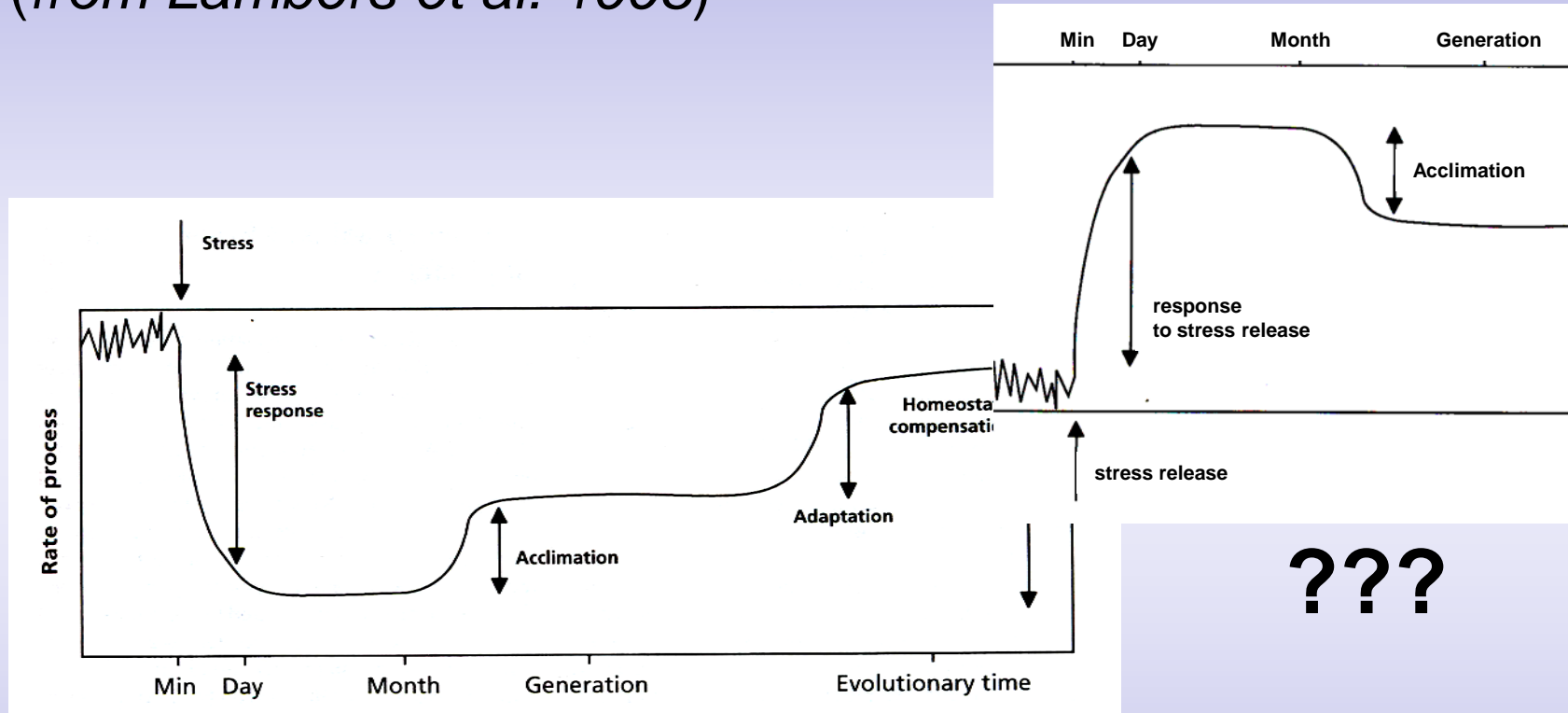
Do cicada larvae inhibit growth of mycorrhizal fungi?



Photo: Randy Molina

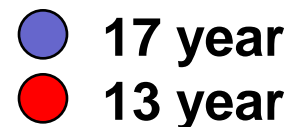
Response of Ecosystem to Stress Pulse:

(from Lambers et al. 1998)



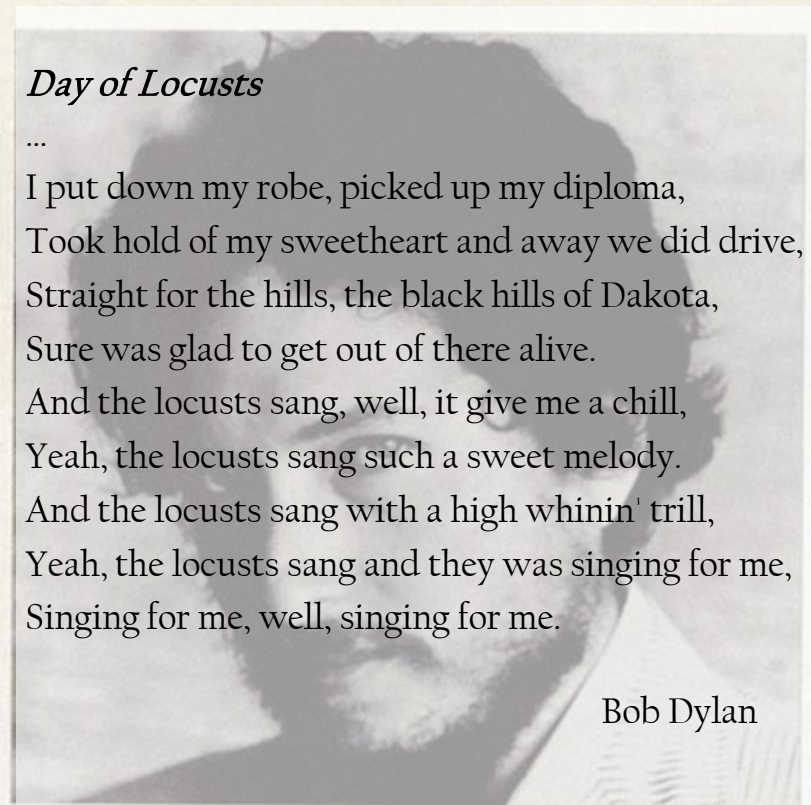
Conclusions

- 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)



Bob Dylan



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