The Year of the "Locust":

Forest-Atmosphere CO_2 Exchange during an Emergence of Periodical Cicada

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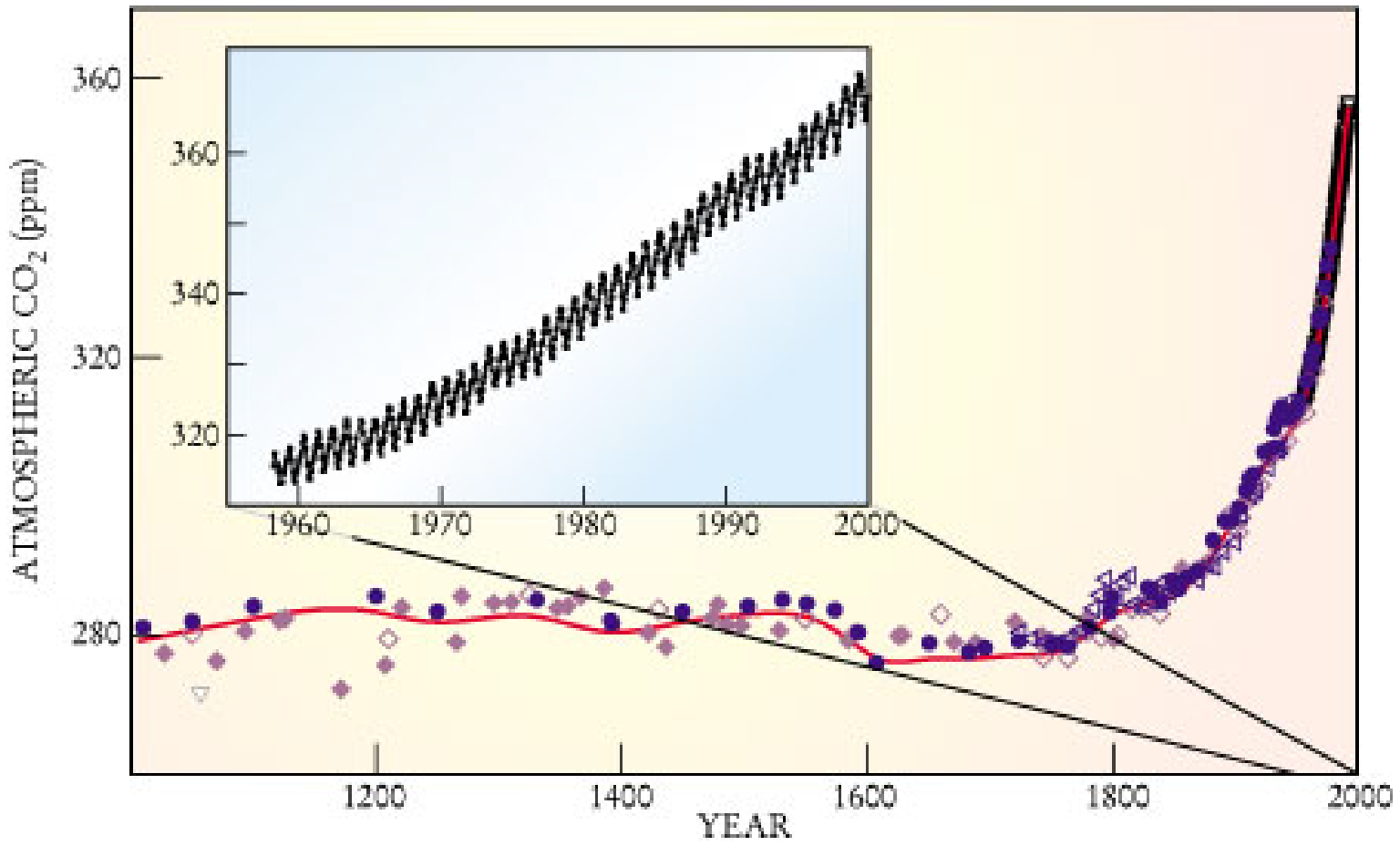
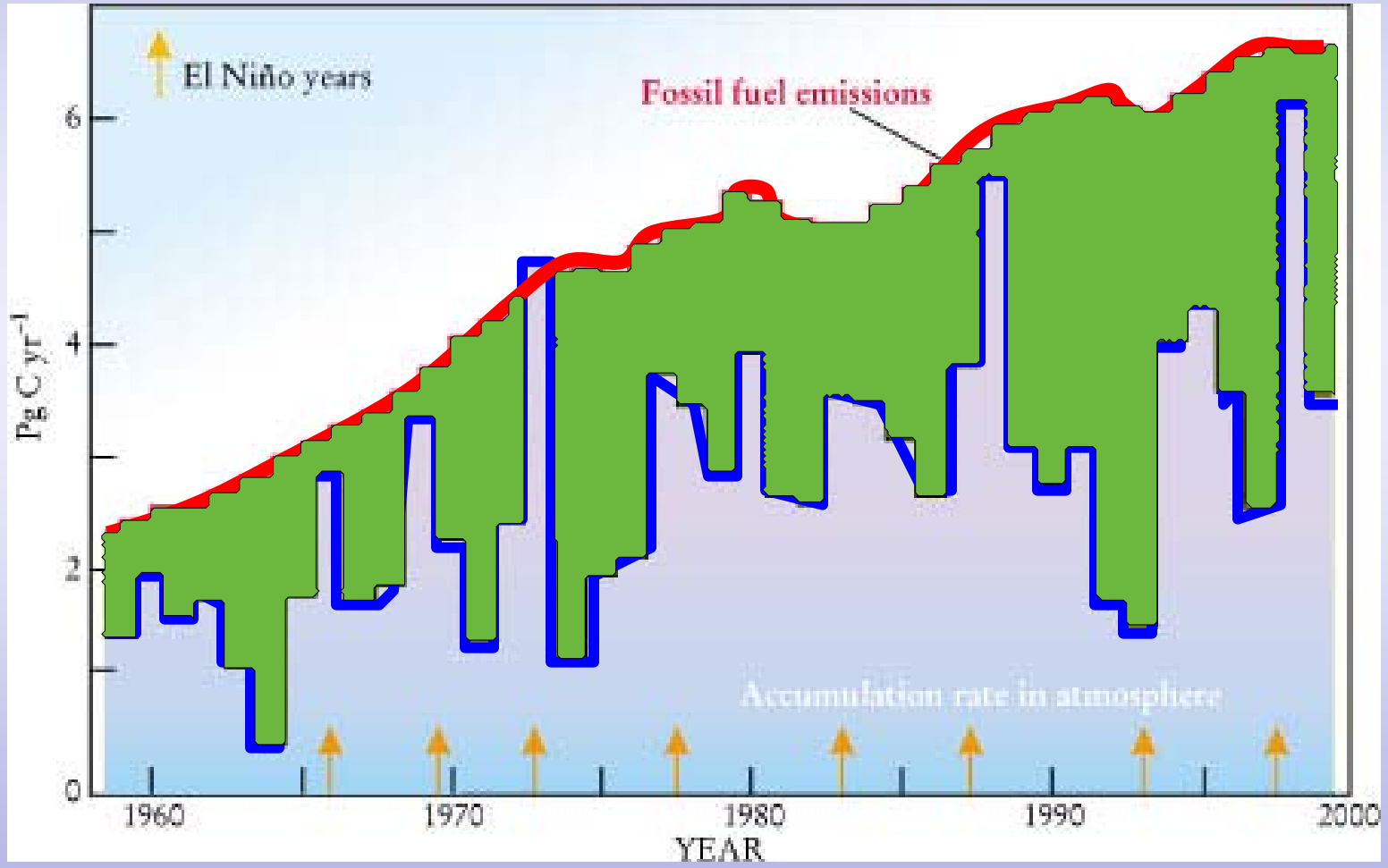
Background: Global Carbon Budget



From: *Sarmiento and Gruber,* 2002 (*Phys. Today*)

Background: Global Carbon Budget

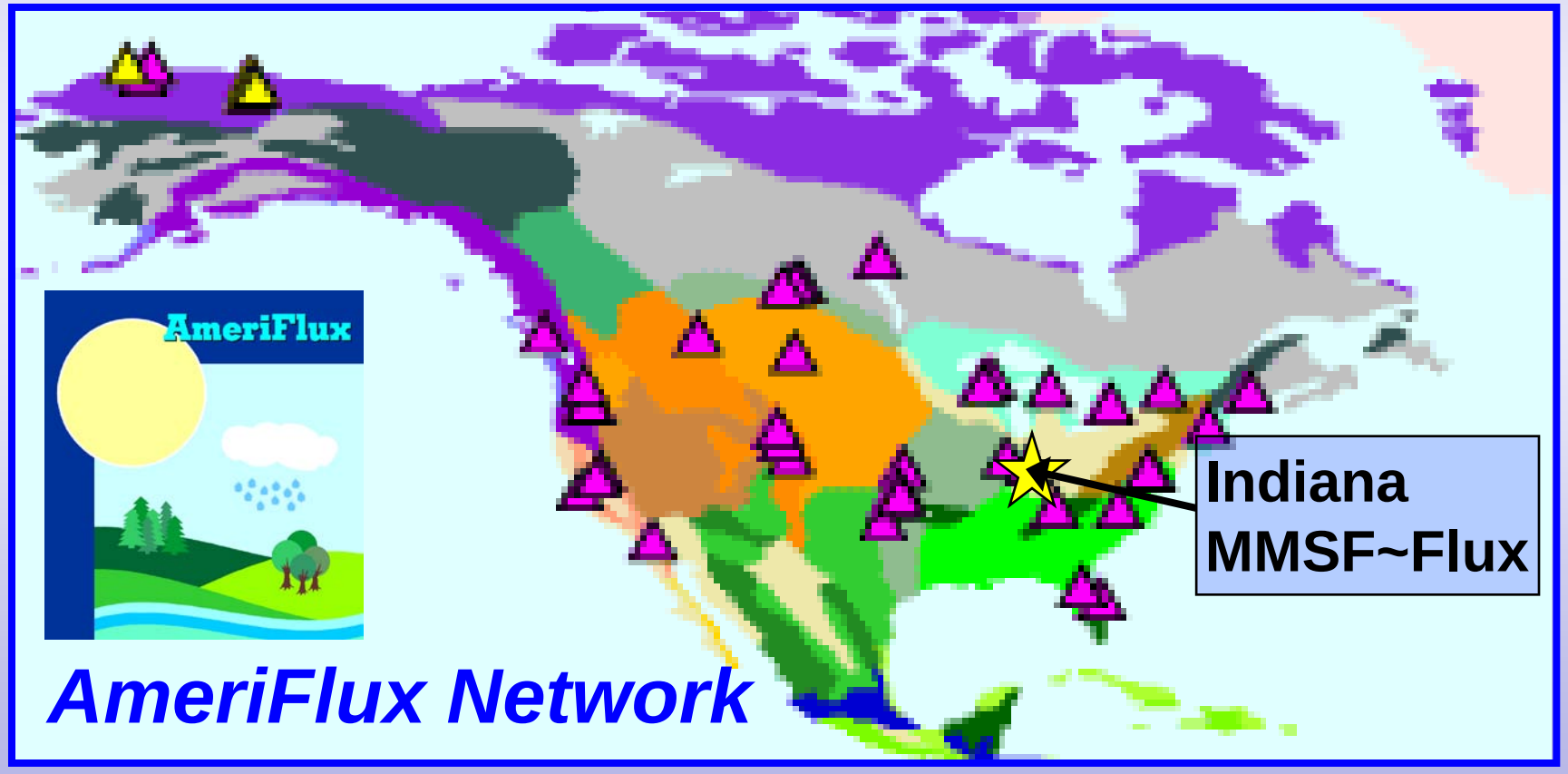
$CO_{2,Atm}$ Accumulation = CO_2 Source - Land & Ocean Sinks



(from Sarmiento and Gruber, 2002)

Site: MMSF AmeriFlux Tower

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



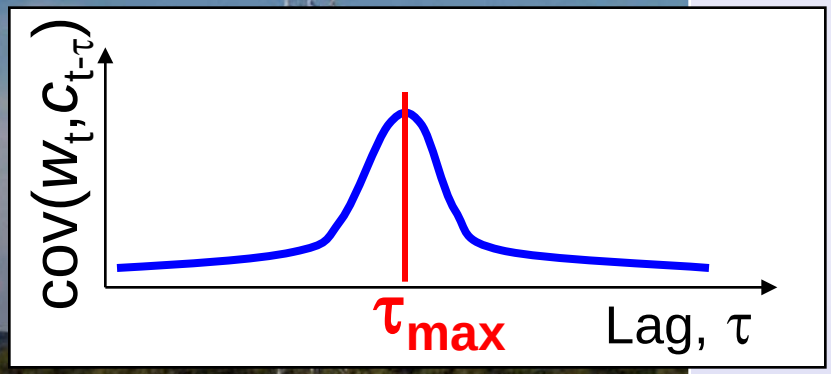
Eddy-Covariance: Closed Path System

AmeriFlux Tower: ~~Instrumentation~~

Eddy-Covariance: $\overline{w'c'} = \mathrm{cov}(w_t, c_t)$

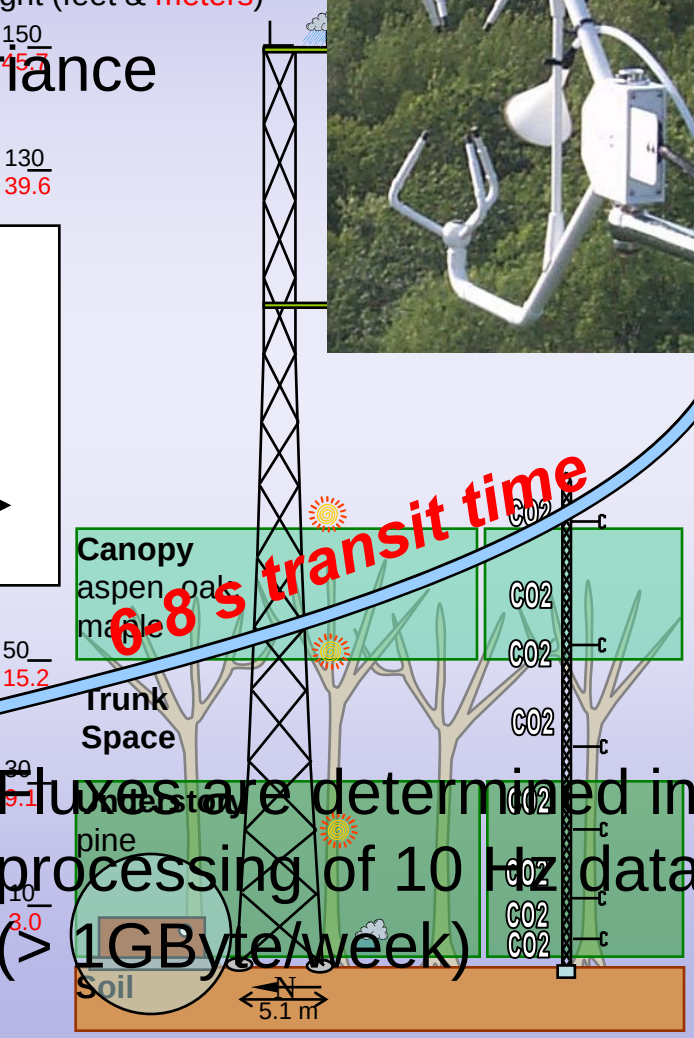
Lagged E-C: $\mathrm{cov}(w_t, c_{t-\tau})$

- τ: determined so that covariance is maximized



GAS

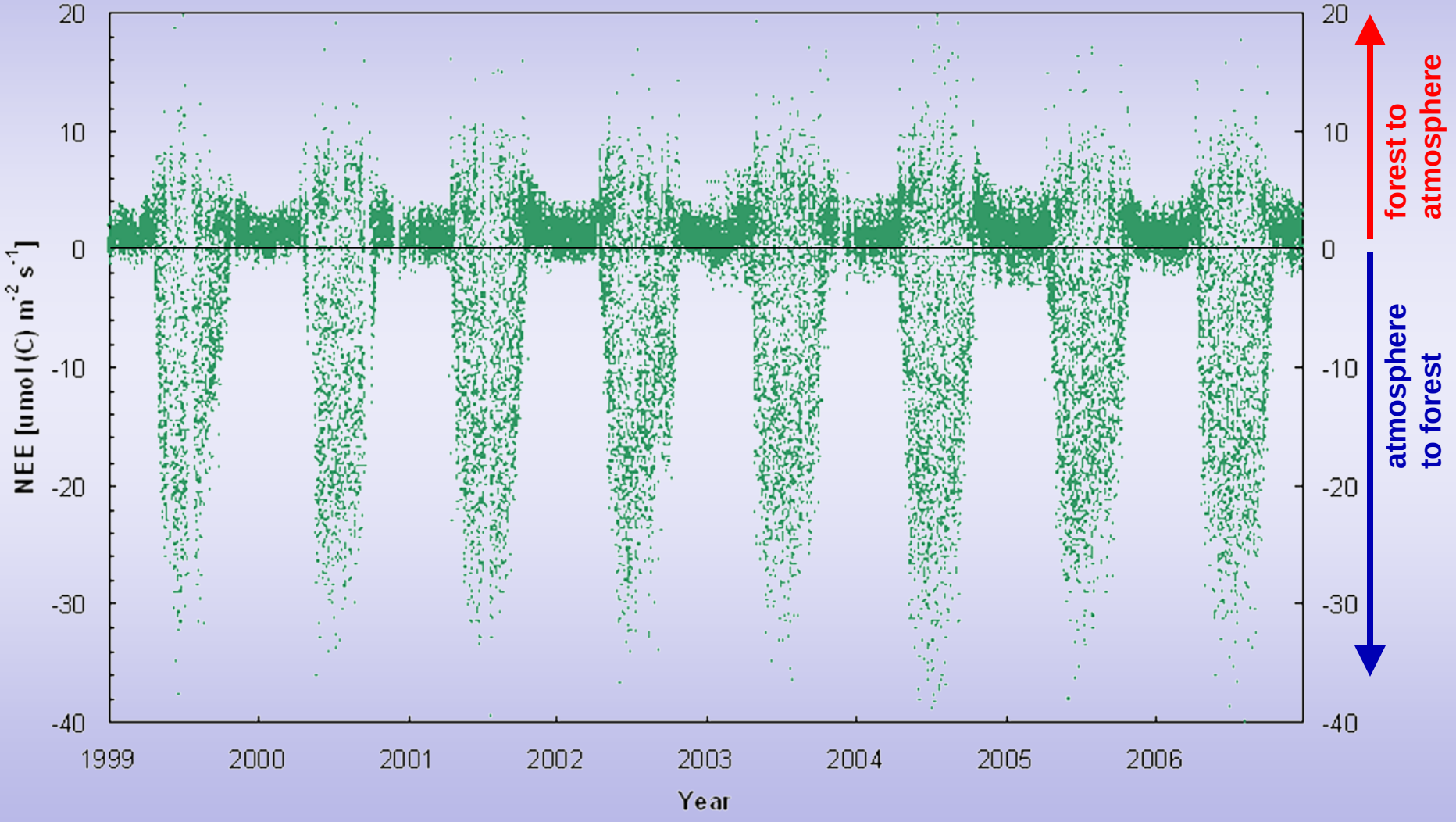
6-8 s transit time



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

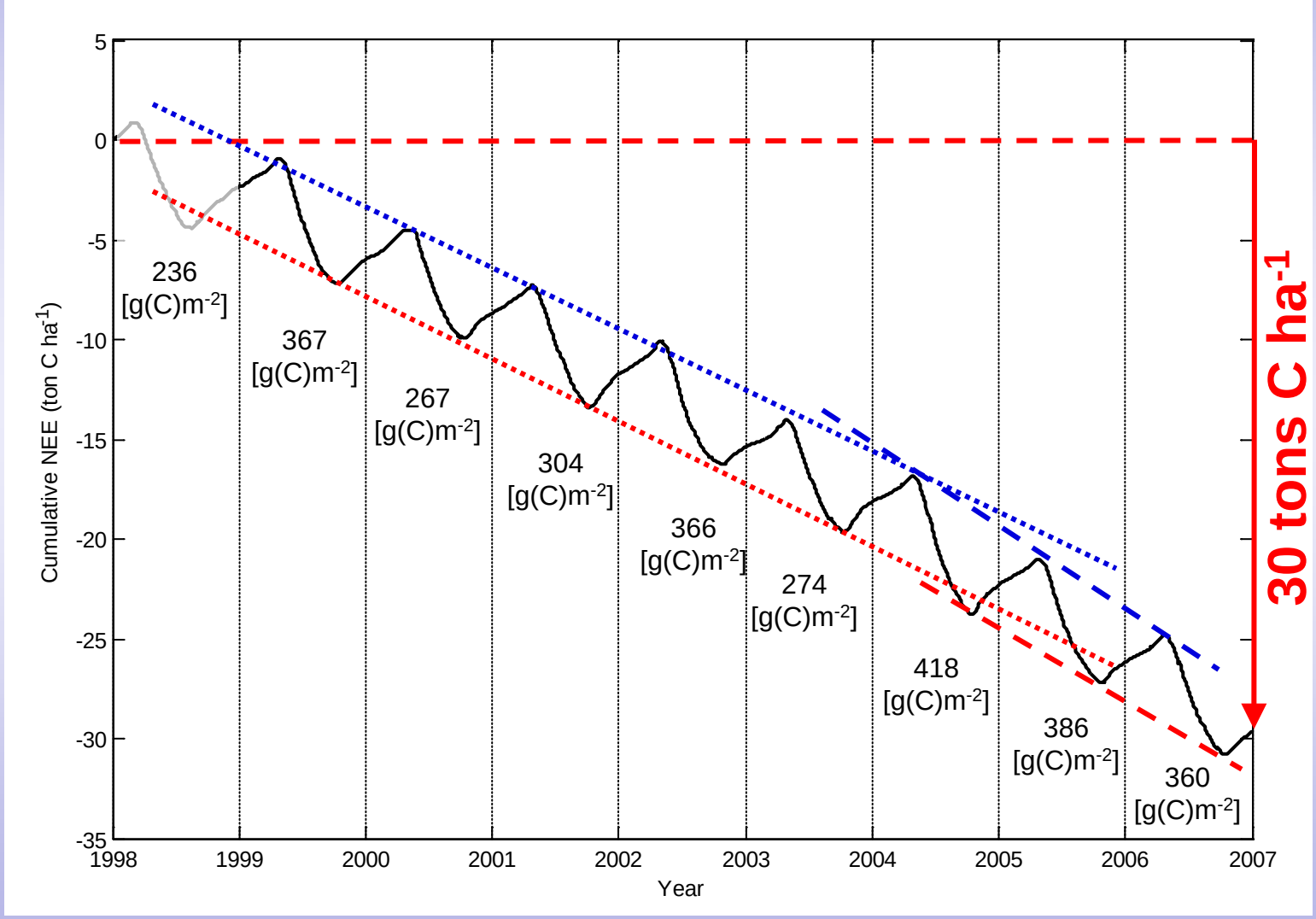
Hourly Fluxes of CO_2 over 8 Years (MMSF)

NEE: *Net Ecosystem Exchange* = Respiration - Assimilation



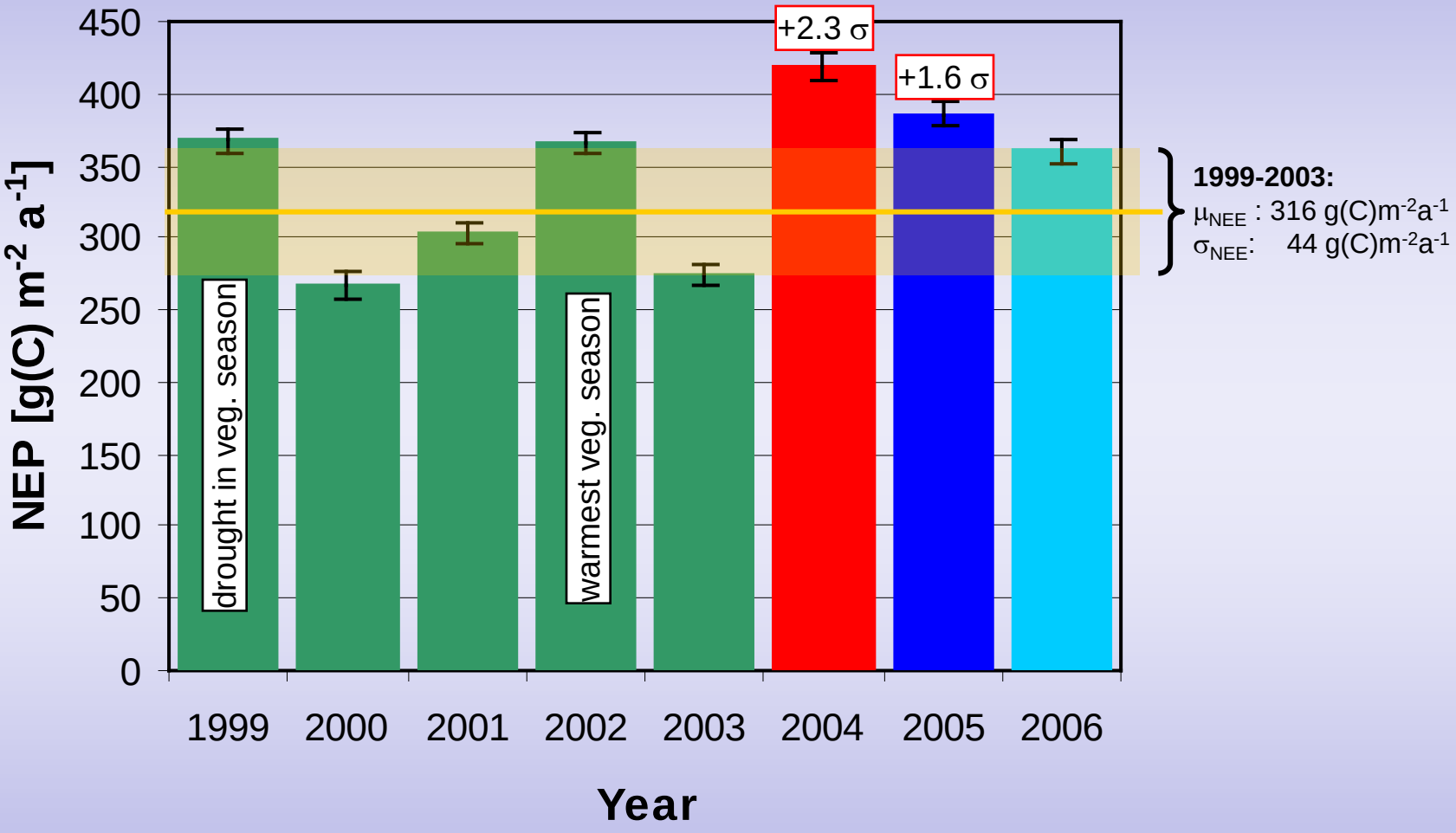
Cumulative Exchange of CO_2 over 9 Years (MMSF)

NEE: *Net Ecosystem Exchange* = Respiration - Assimilation



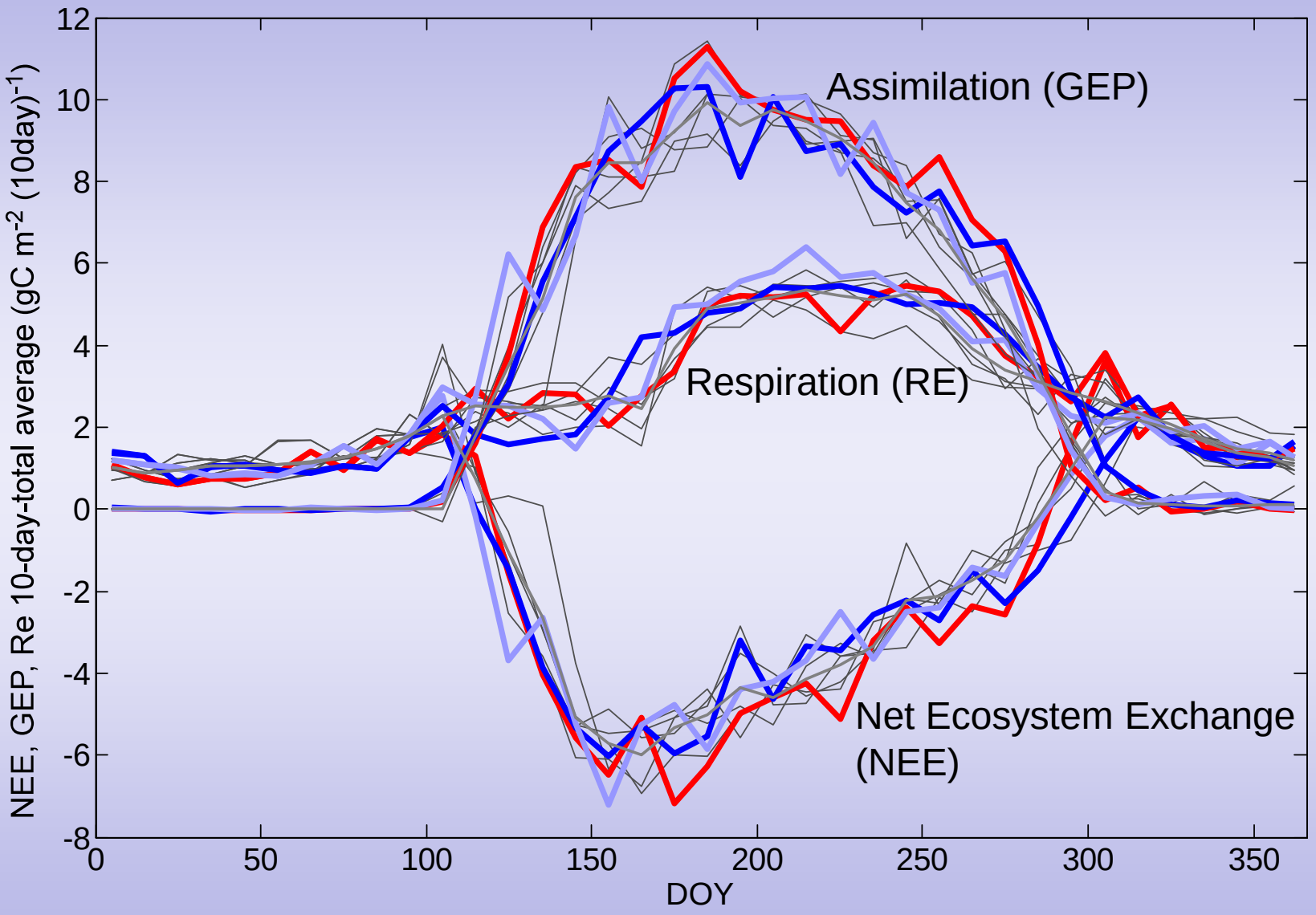
30 tons C ha^{-1} = 3 kg C m^{-2}

Annual Net Ecosystem Production (NEP)



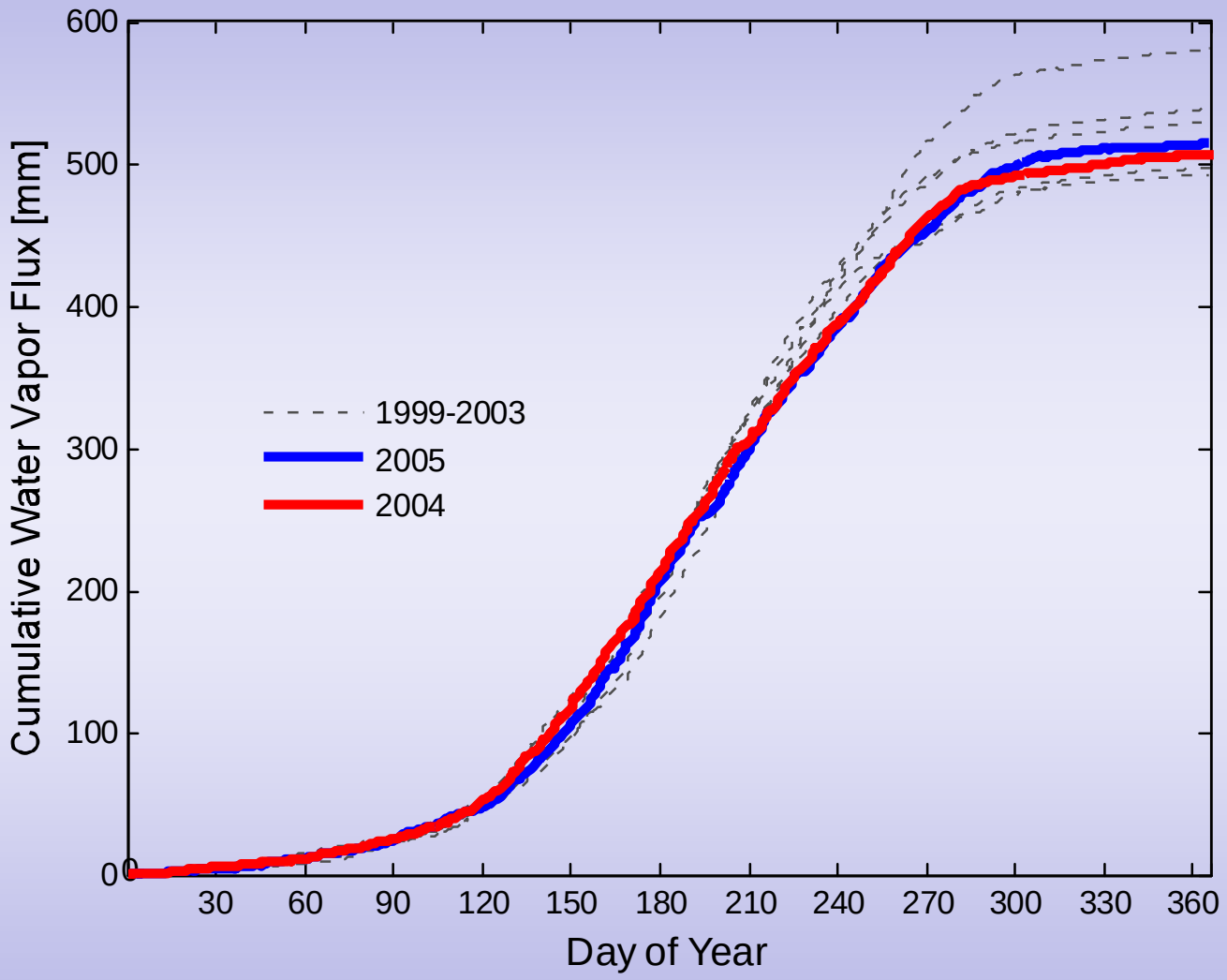
- all data re-analyzed (consistent methods)
- (random) uncertainty estimate by Monte-Carlo method

-NEP = NEE = RE - GEP



- **2004 NEE "pulse" is due to GEP, not RE**

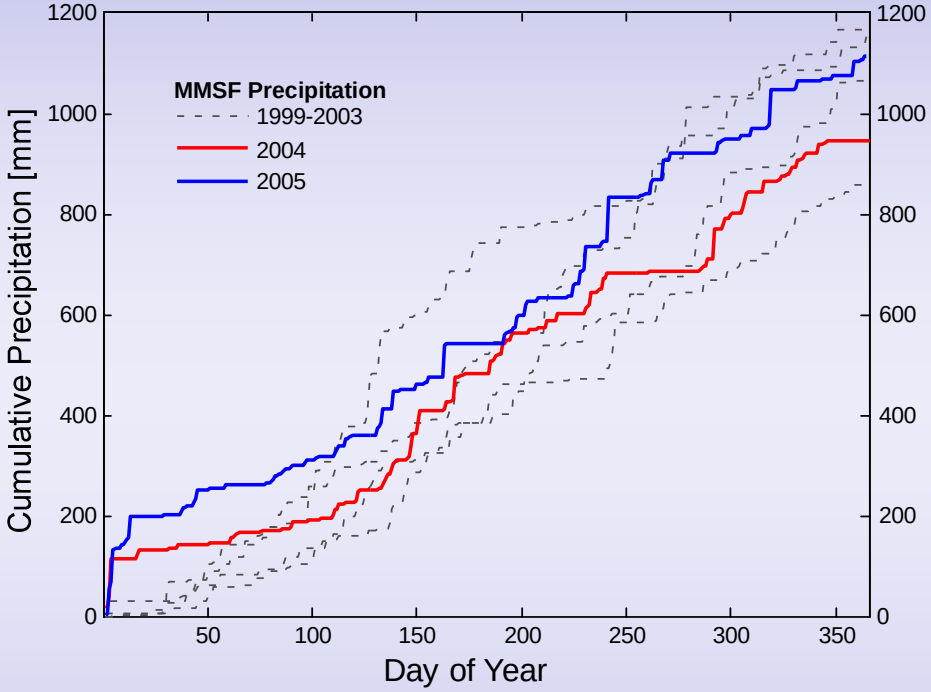
Water Vapor Flux



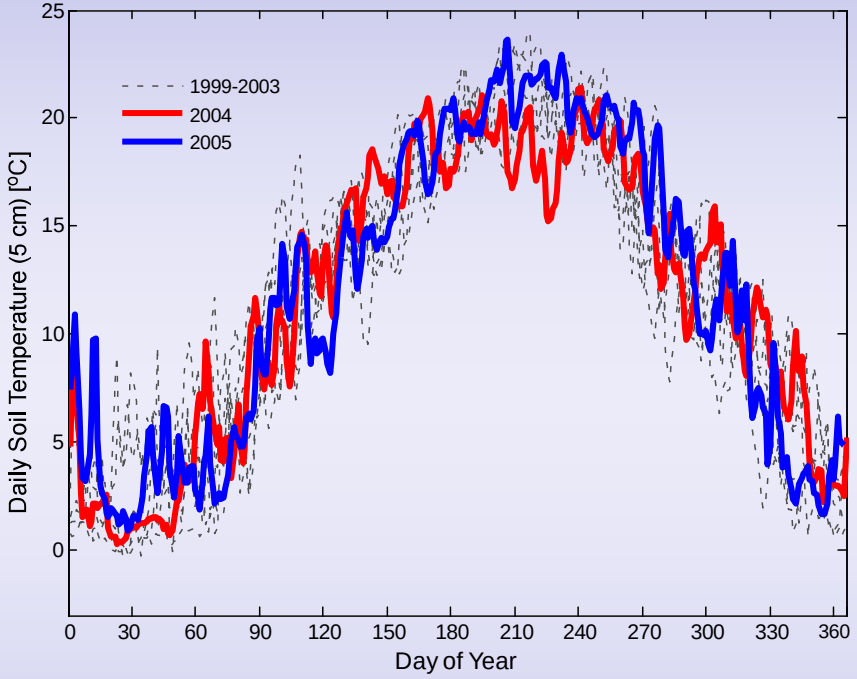
- **2004/2005 are “normal”**

Were 2004 & 2005 Climatically Unusual?

Precipitation



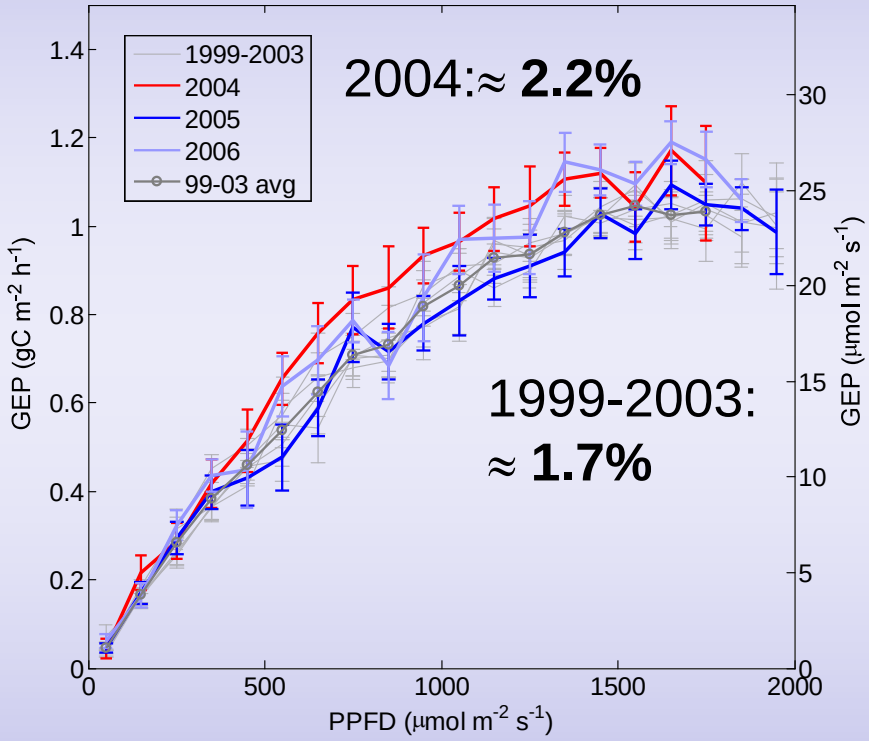
Soil Temperature



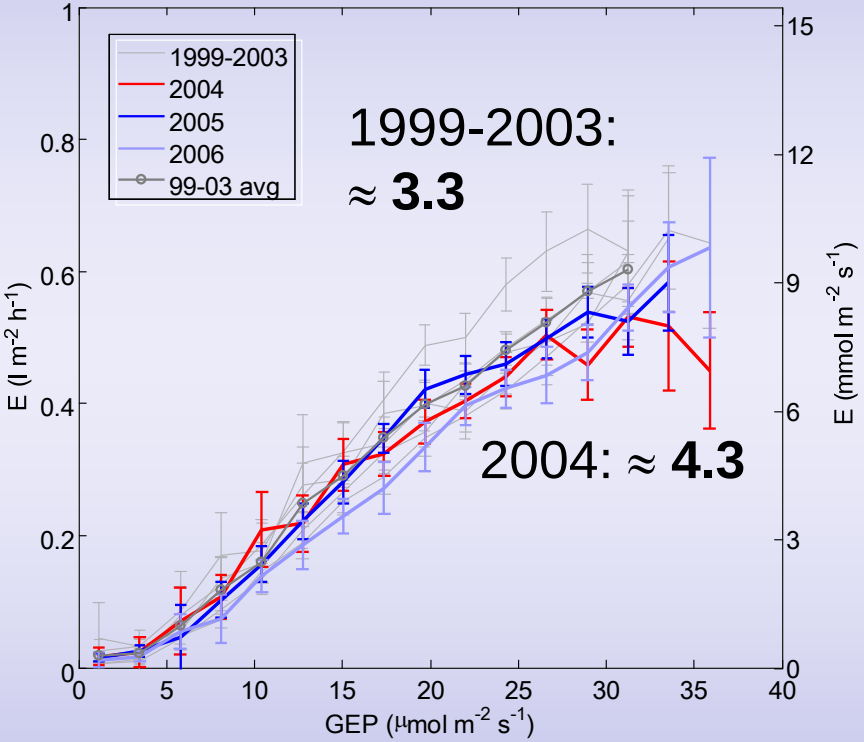
- 2004 & 2005 do not stand out **climatically**
- (2004 rather low in PAR, average T_{air})
- NEE “pulse” is not due to climatic forcing

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

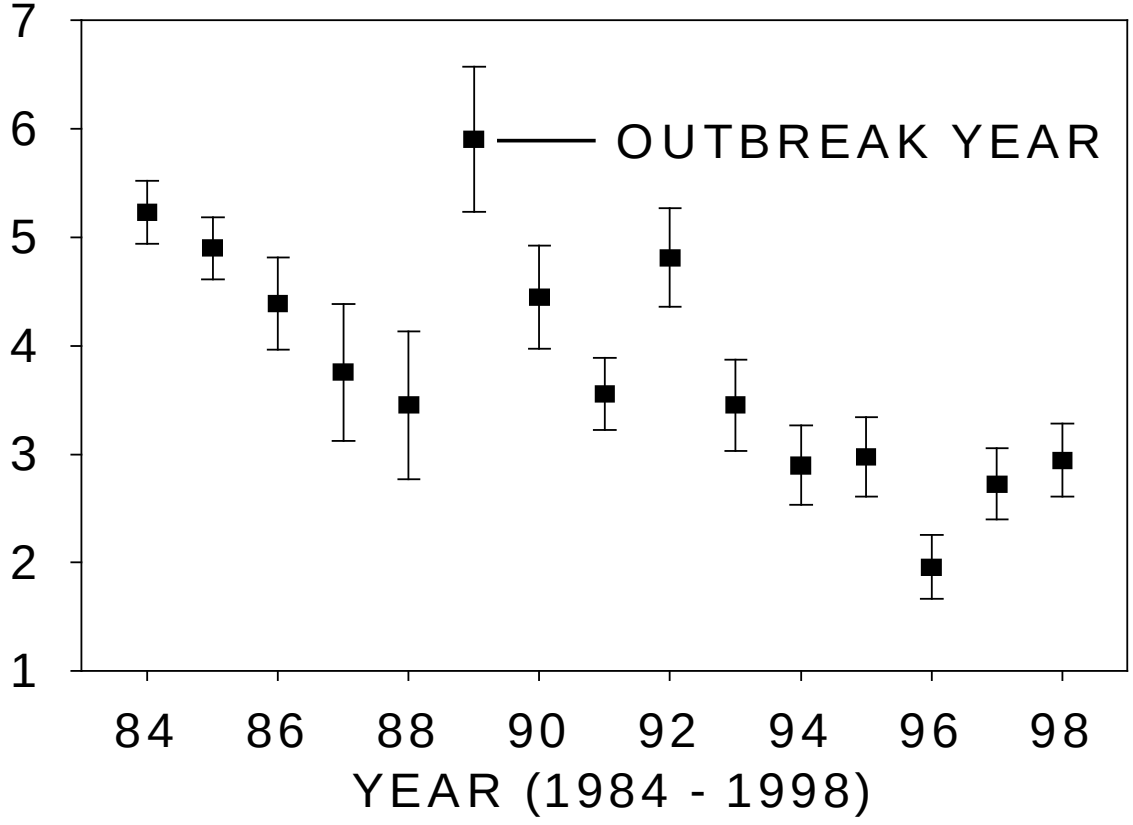
- 17 years or 13 years
- Brood X (17 yr) is largest
- IN,IL,OH,KY; centered on southern Indiana
- other branch in DC area

- 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



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} (≈ ½ 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):

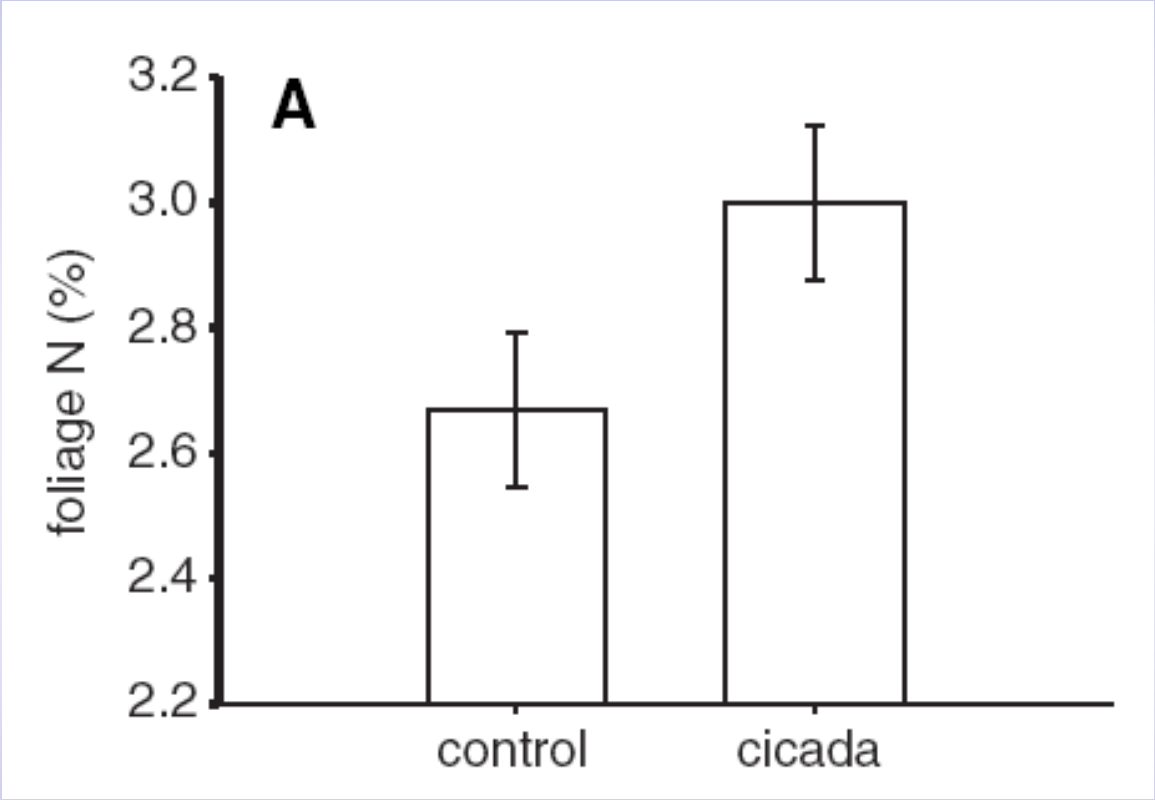
- with ~ 3.74 % N in cicada mass: **~ 7.5 kg N ha^{-1}**
  "loss" due to foraging ~70%? Immobilized how long?

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: ≈ 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

$\Rightarrow$ 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?

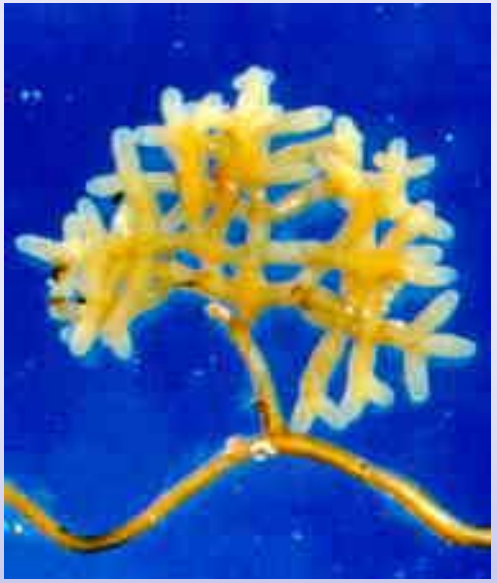
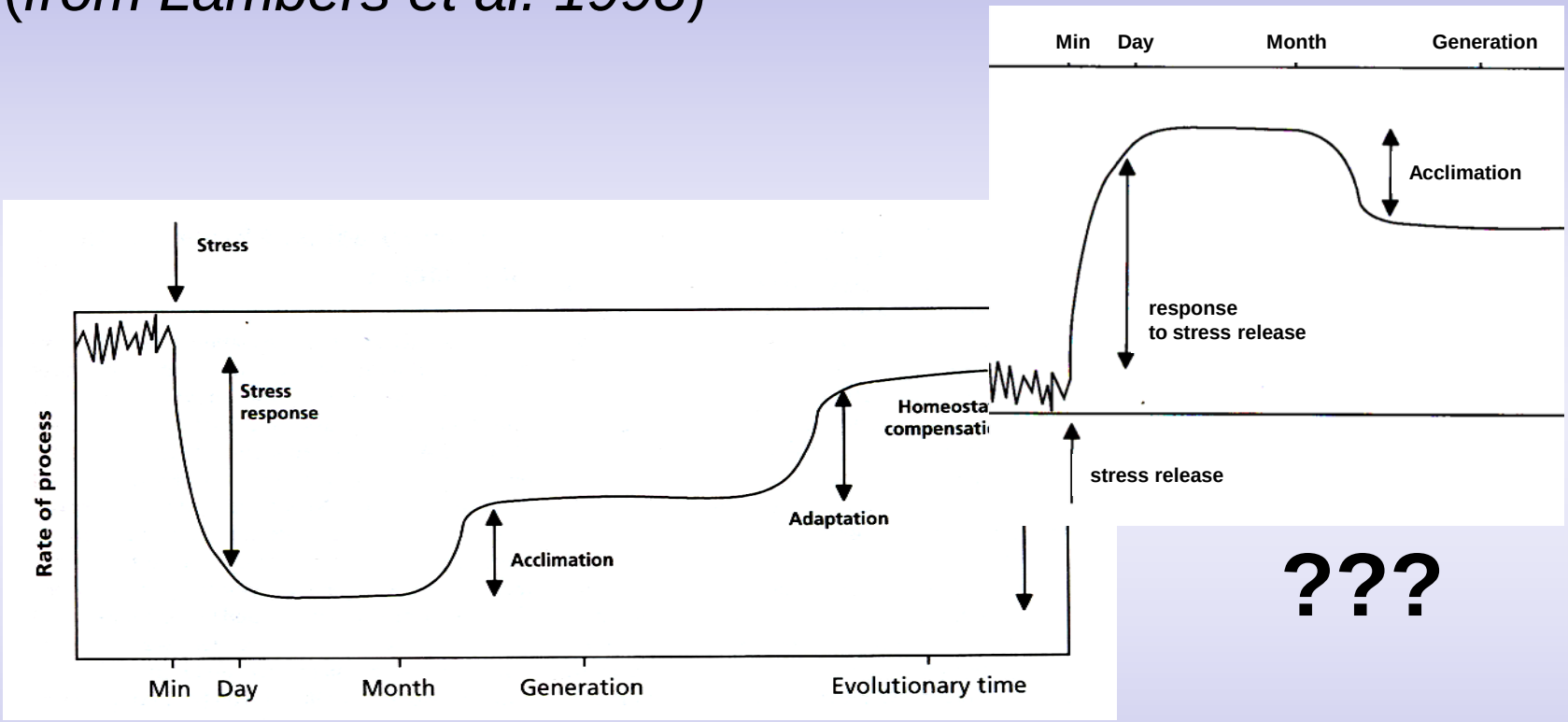


Photo: Randy Molina

Response of Ecosystem to Stress Pulse:

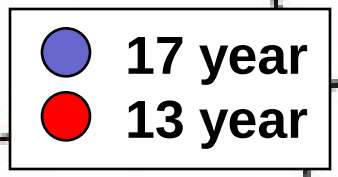
(*from Lambers et al. 1998*)



???

Conclusions

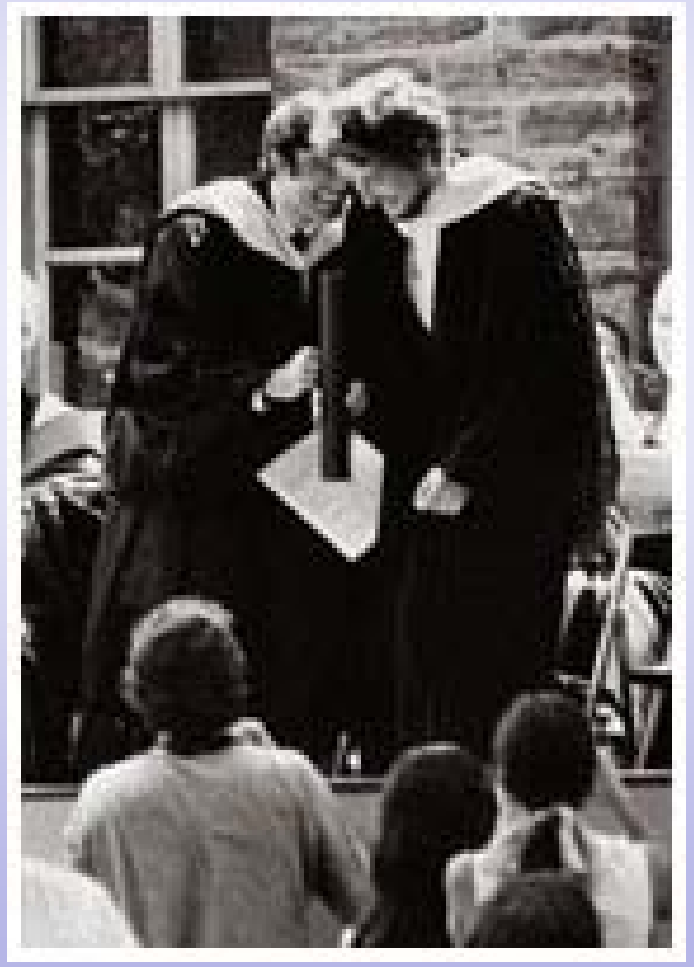
- Periodical Cicada have large areal coverage in eastern United States
- Cicada induced pulse in NEE is potentially a large-scale phenomenon
- Large scale implications on terrestrial carbon budget
- Detected by micrometeorological methods: spatial aggregate sampling of eddy-covariance

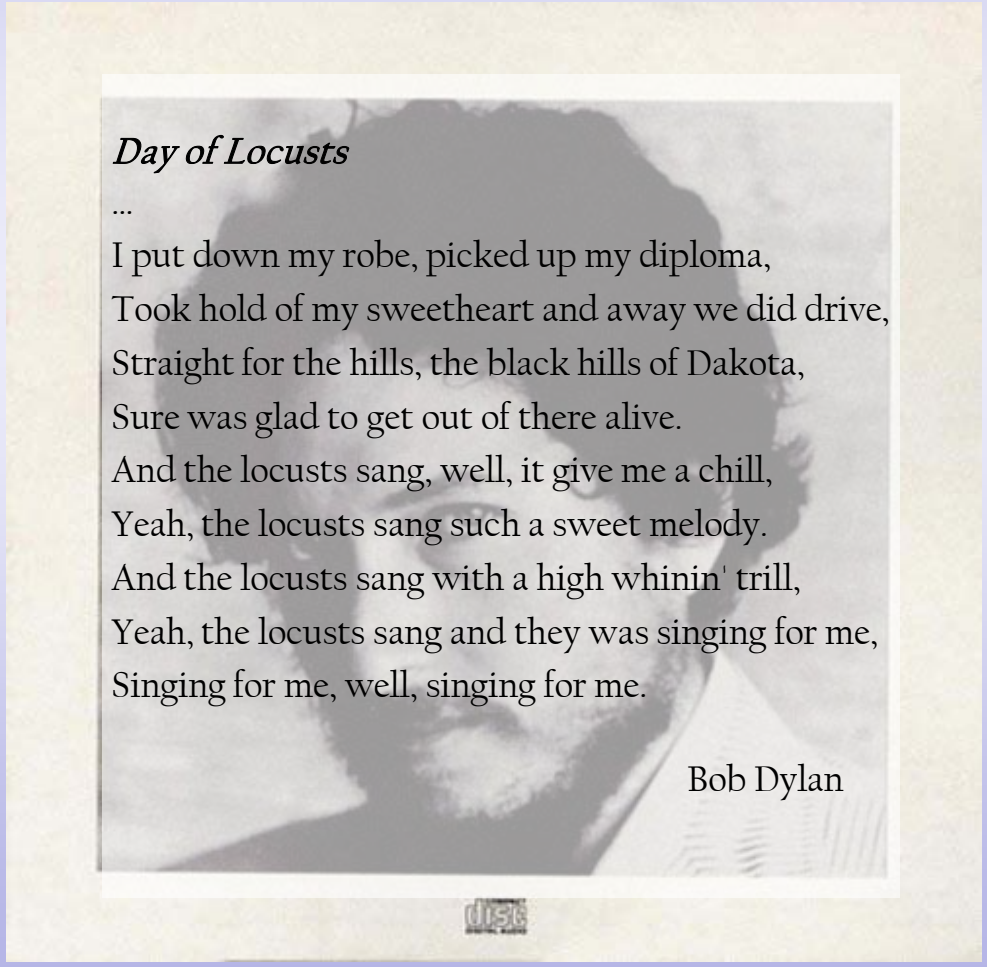


http://members.fortunecity.com/cicadaman1999/id47.htm

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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