Lessons from Harvard Forest

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And a multitude of key collaborators over the decades

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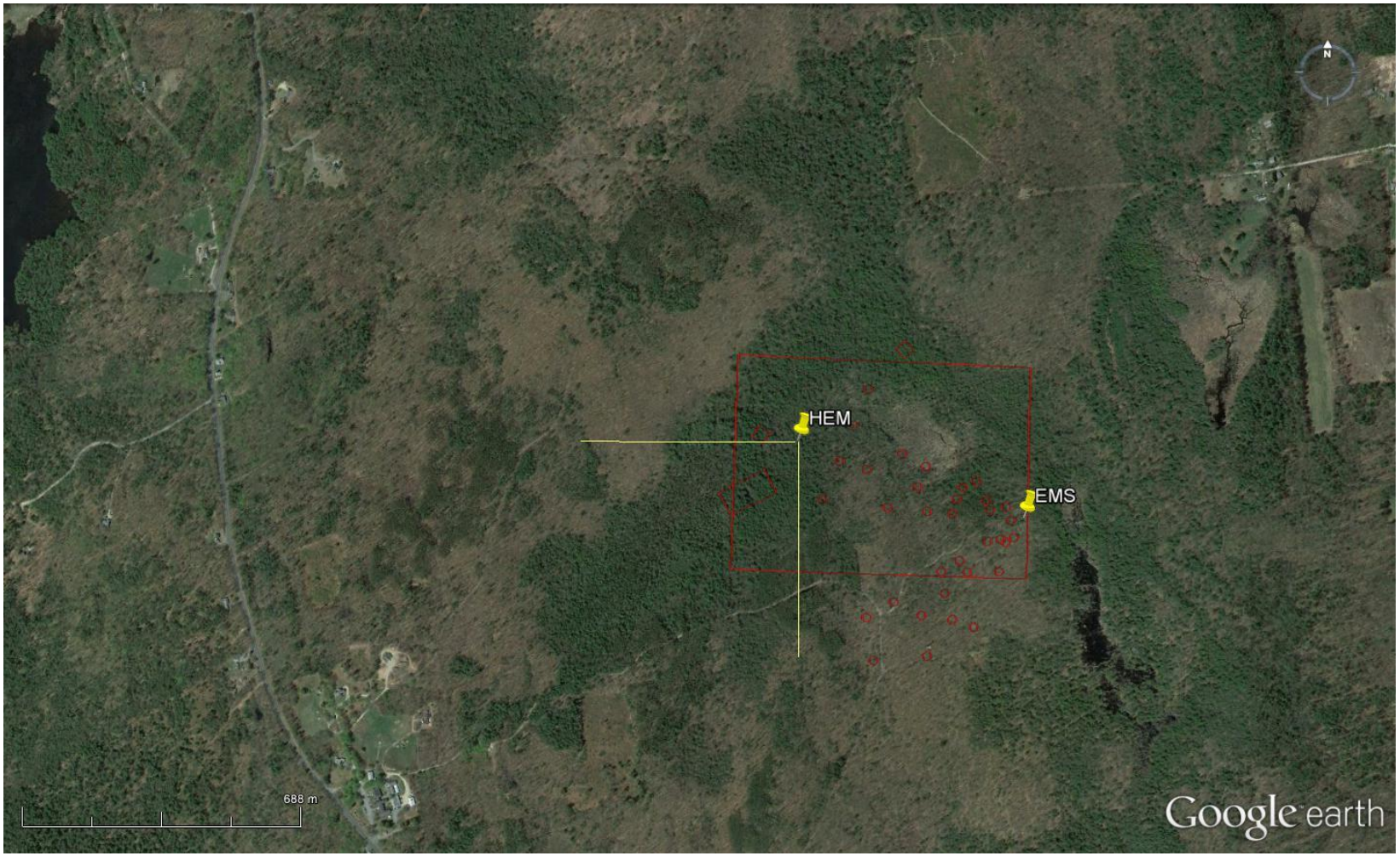
HARVARD
School of Engineering and Applied Sciences

HARVARD FOREST
Established 1907
Harvard University's 3500 acre laboratory & classroom
Long Term Ecological Research Site since 1988

AMERIFLUX

LTER



Flux tower sites are embedded in a large expanse of mostly intact forest that is a mosaic of oak/maple and hemlock stands

Red dots and polygons are vegetation survey plots

Why make long-term studies?

Trees grow slowly, requiring long-term data to detect response to climate and succession

25 years is major part of a research career, but short time for forest ecosystem response

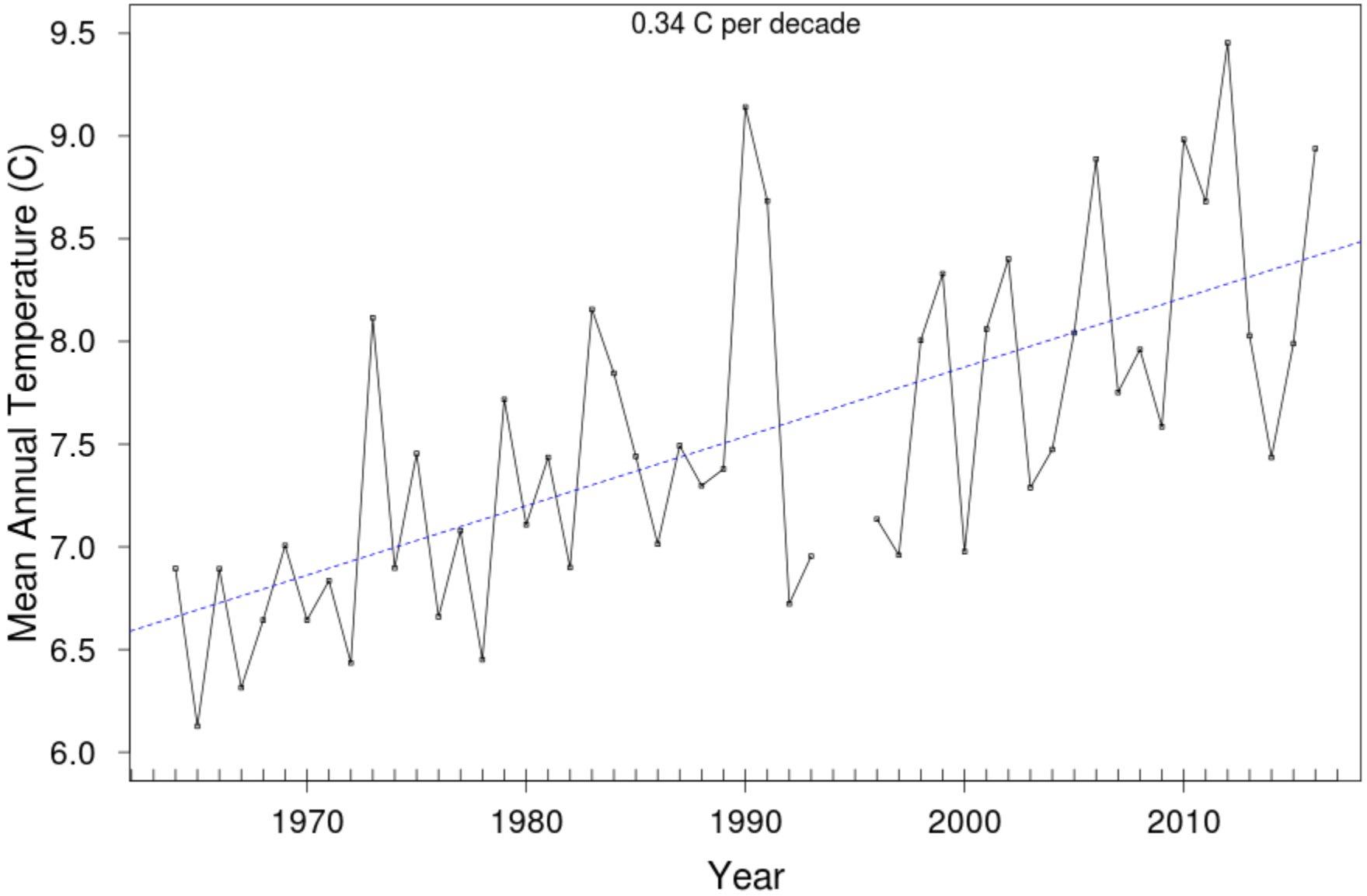
Long time to get a climate signal that exceeds interannual variability

The pace of ecosystem change in large-stature vegetation is slow

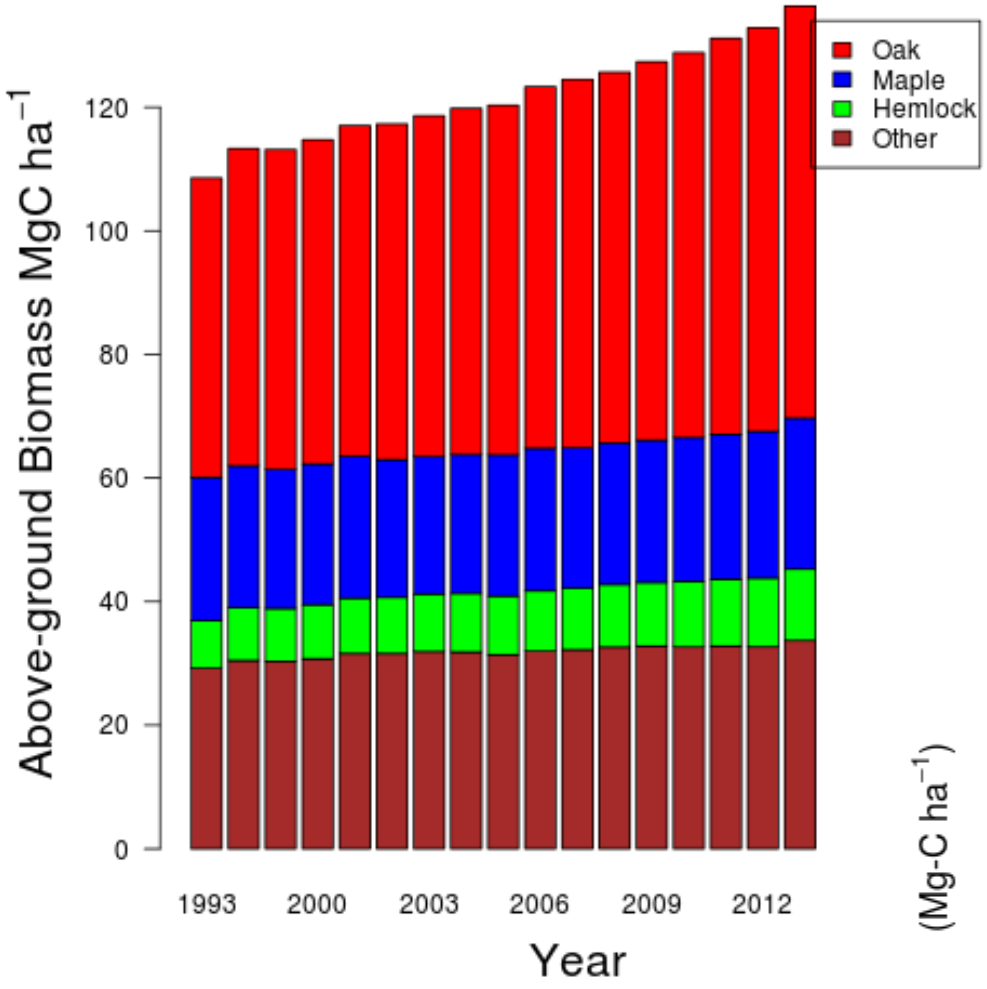
Turnover times for major carbon pools are decade to century

Need to observe the influence of infrequent but high-impact events

Harvard Forest weather station data

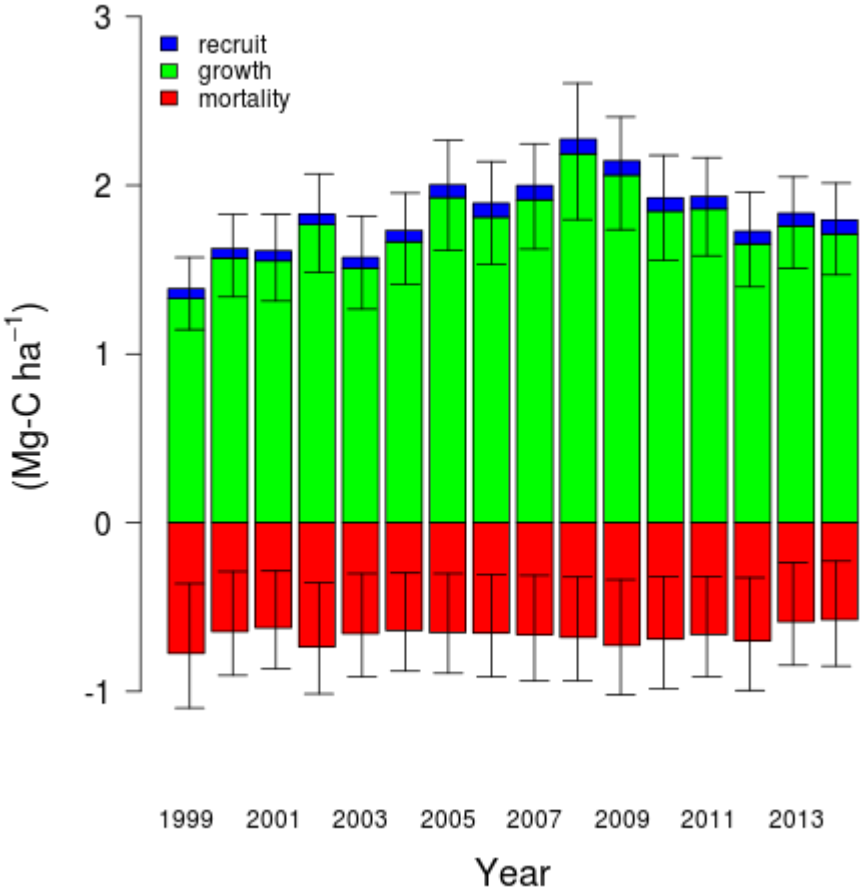


Significant variability in seasonal climate conditions are contained within the variable annual mean T. Notably, snowpack depth and duration vary widely along with freeze/thaw transition.

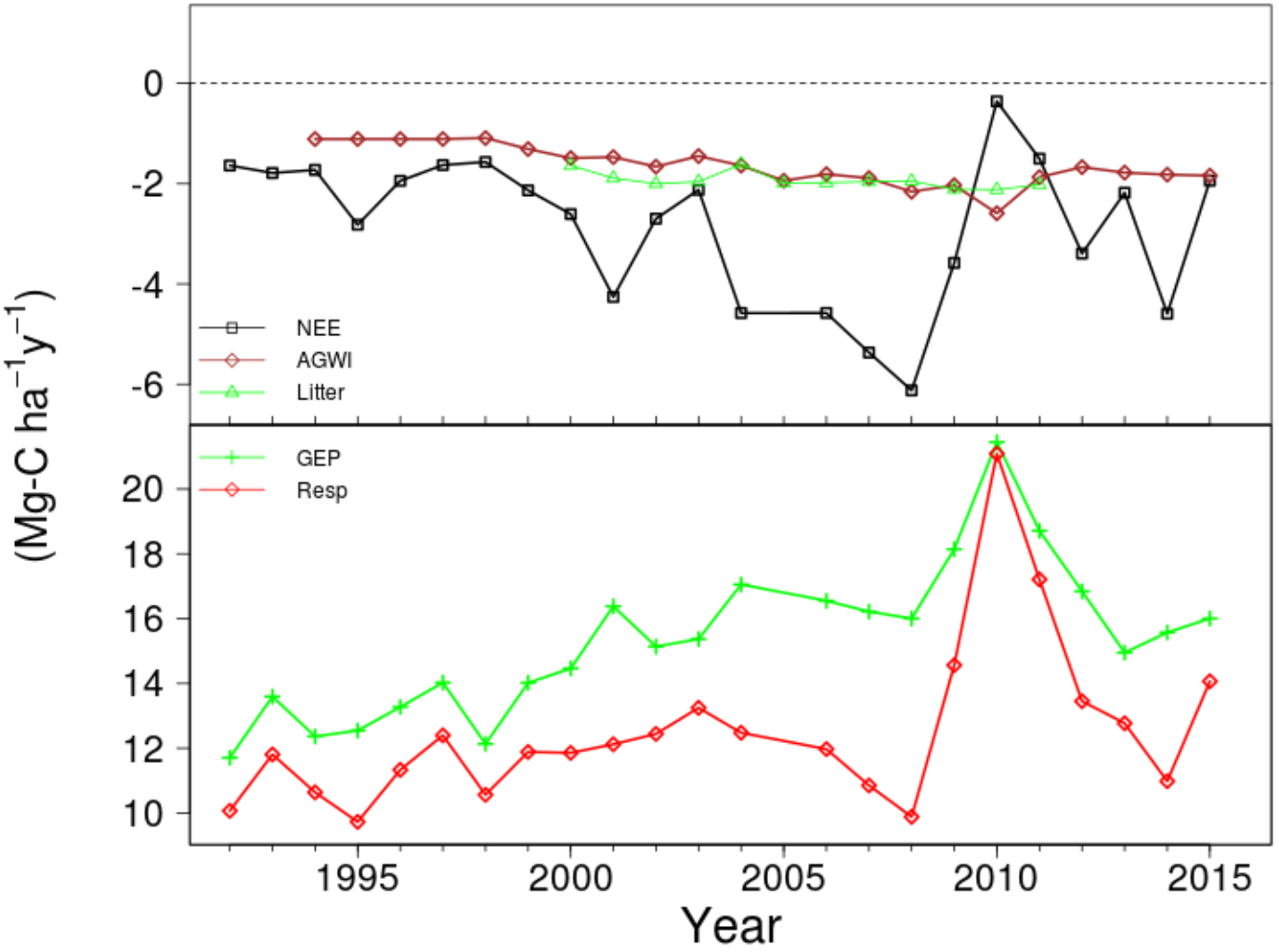


Oaks dominate the woody biomass growth.

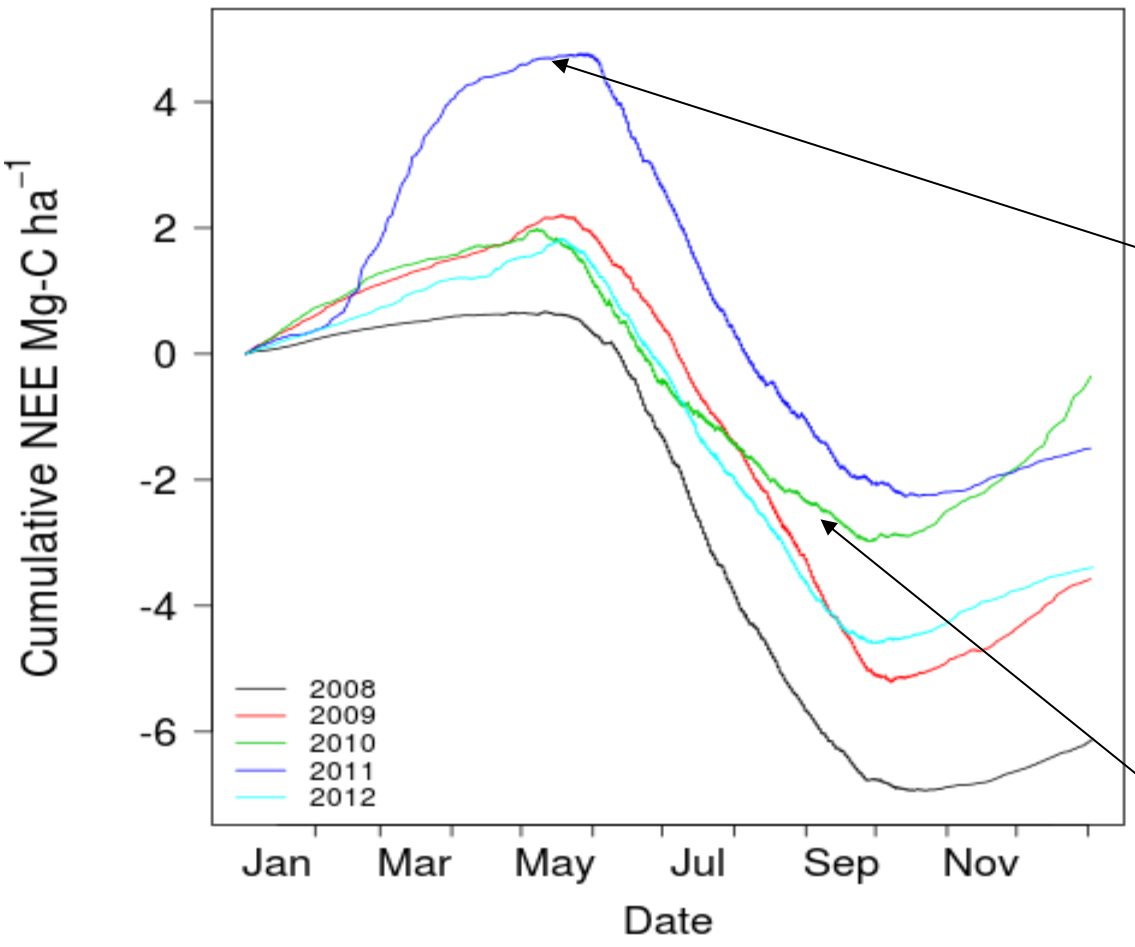
Hemlock abundance has increased relative to its starting point as small trees reach 10cm, but its overall biomass averaged over footprint is small.



Most of the trees in the forest now were present in 1991. A few have died, and some that were saplings are big enough to be counted now. Few if any trees present today sprouted since the start of measurements.



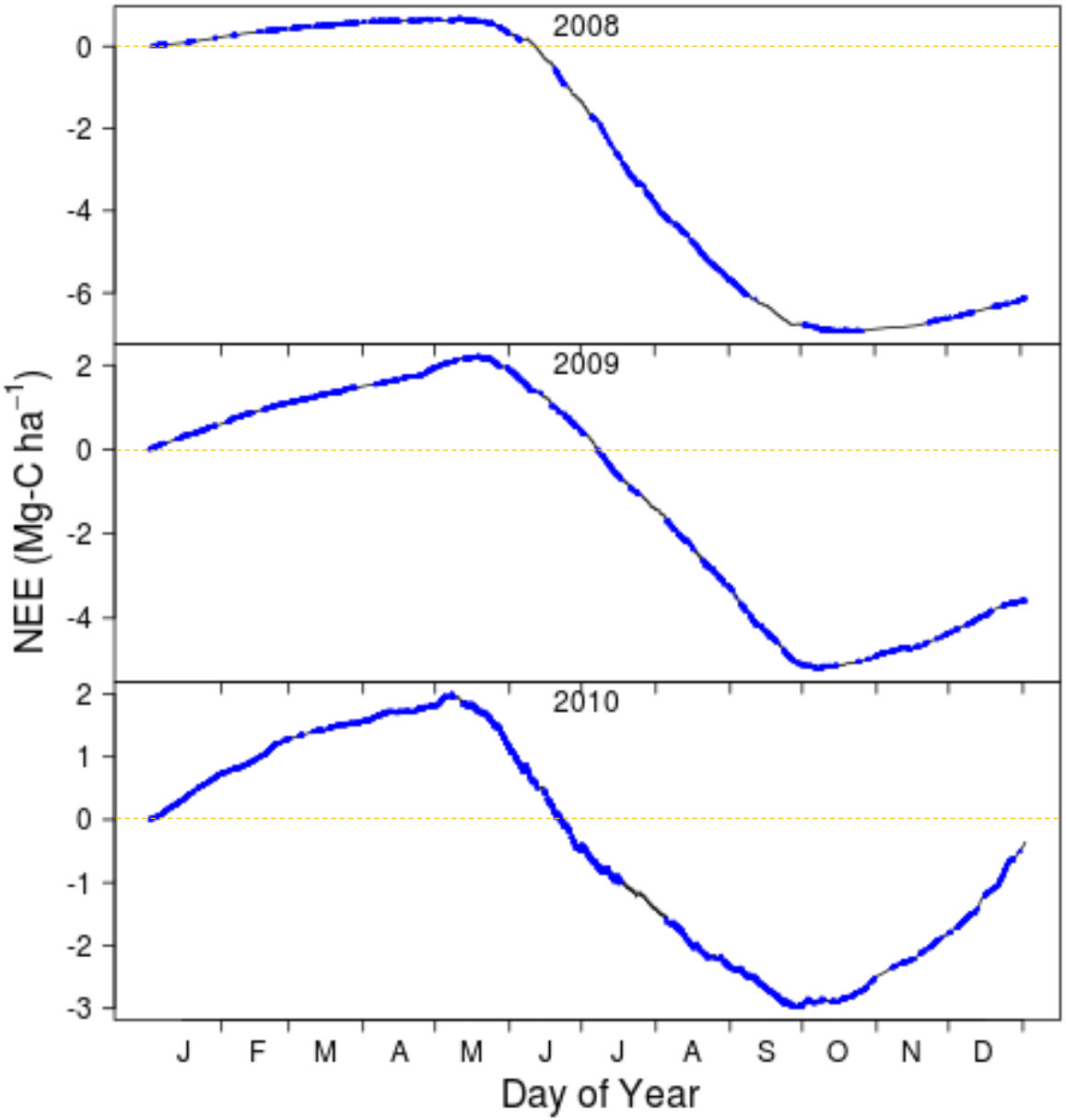
Annual NEE has been very dynamic in the most recent decade.
Similar dynamics but some difference in magnitude for fluxnet version.
Annual NEE is difficult to interpret; need to focus in on patterns within seasons and try to interpret based on valid observations alone.



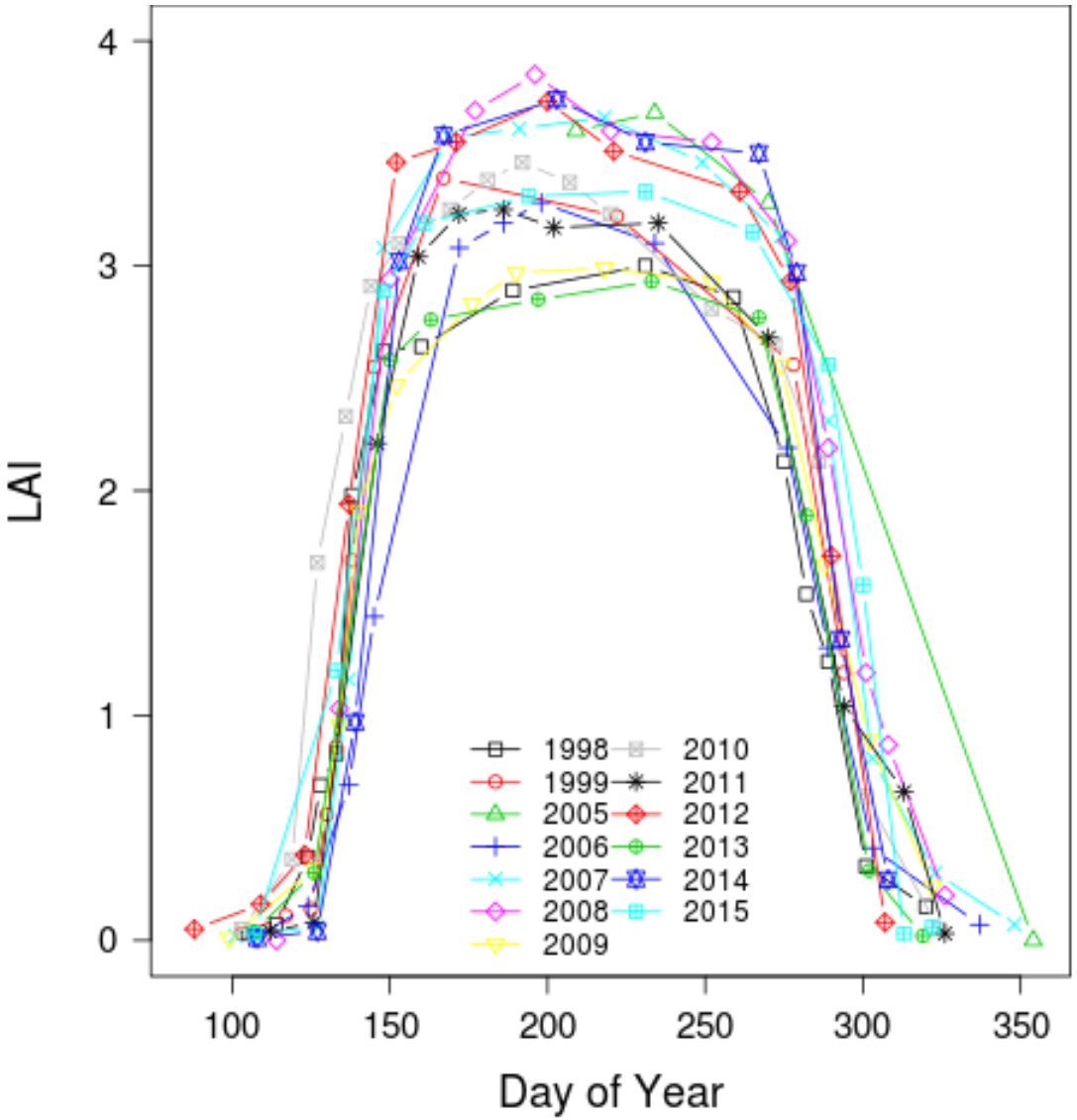
Anomalously high respiration during winter 2011

Magnitude of 2010 growing season uptake is reduced

An exceptionally dry summer



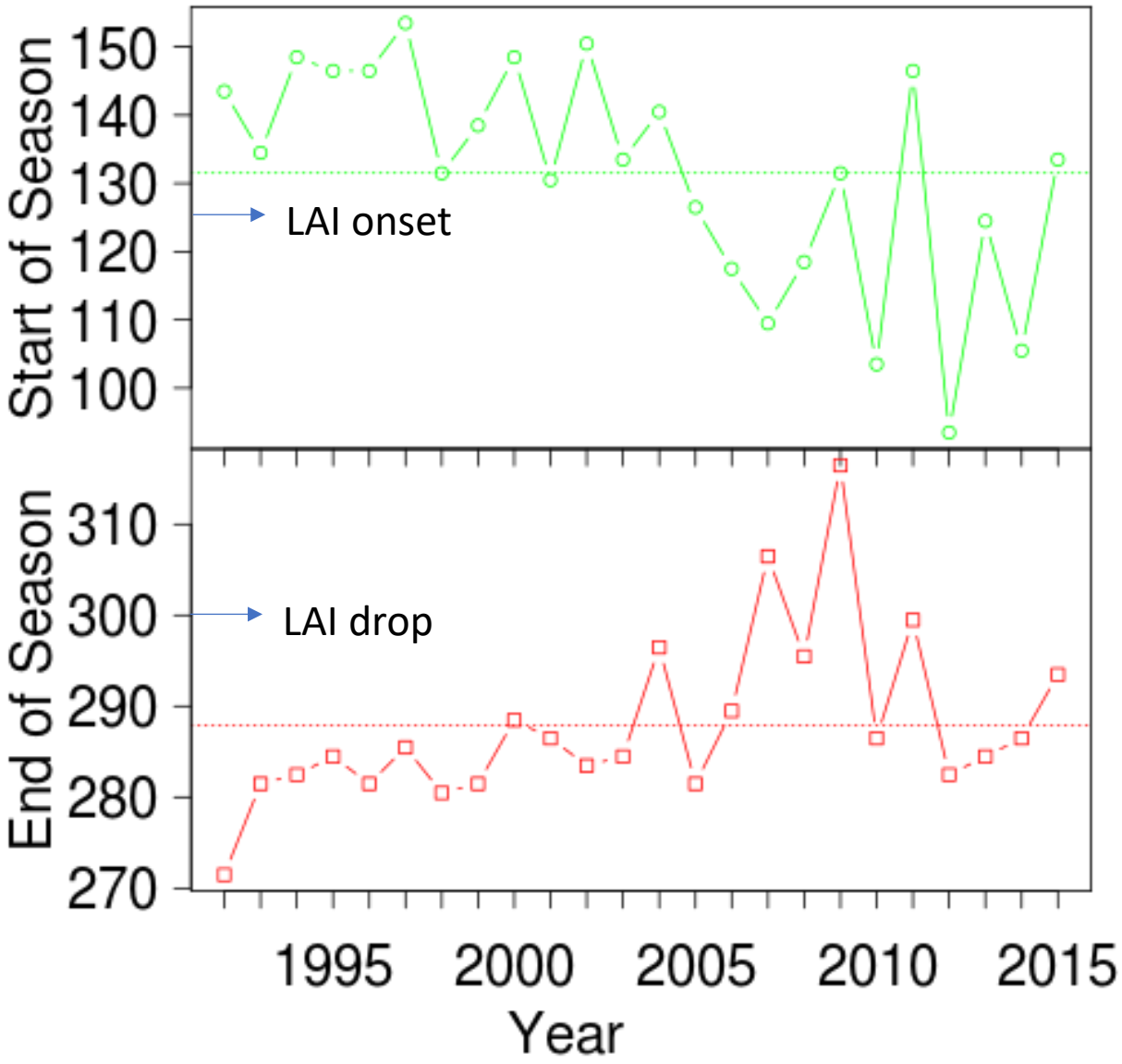
Cumulative NEE is plotted here with the valid observations highlighted in blue. Clearly some lengthy intervals are composed primarily of filled data, but the filling matches up with expected slopes. Importantly, the inflection points are captured by valid observations



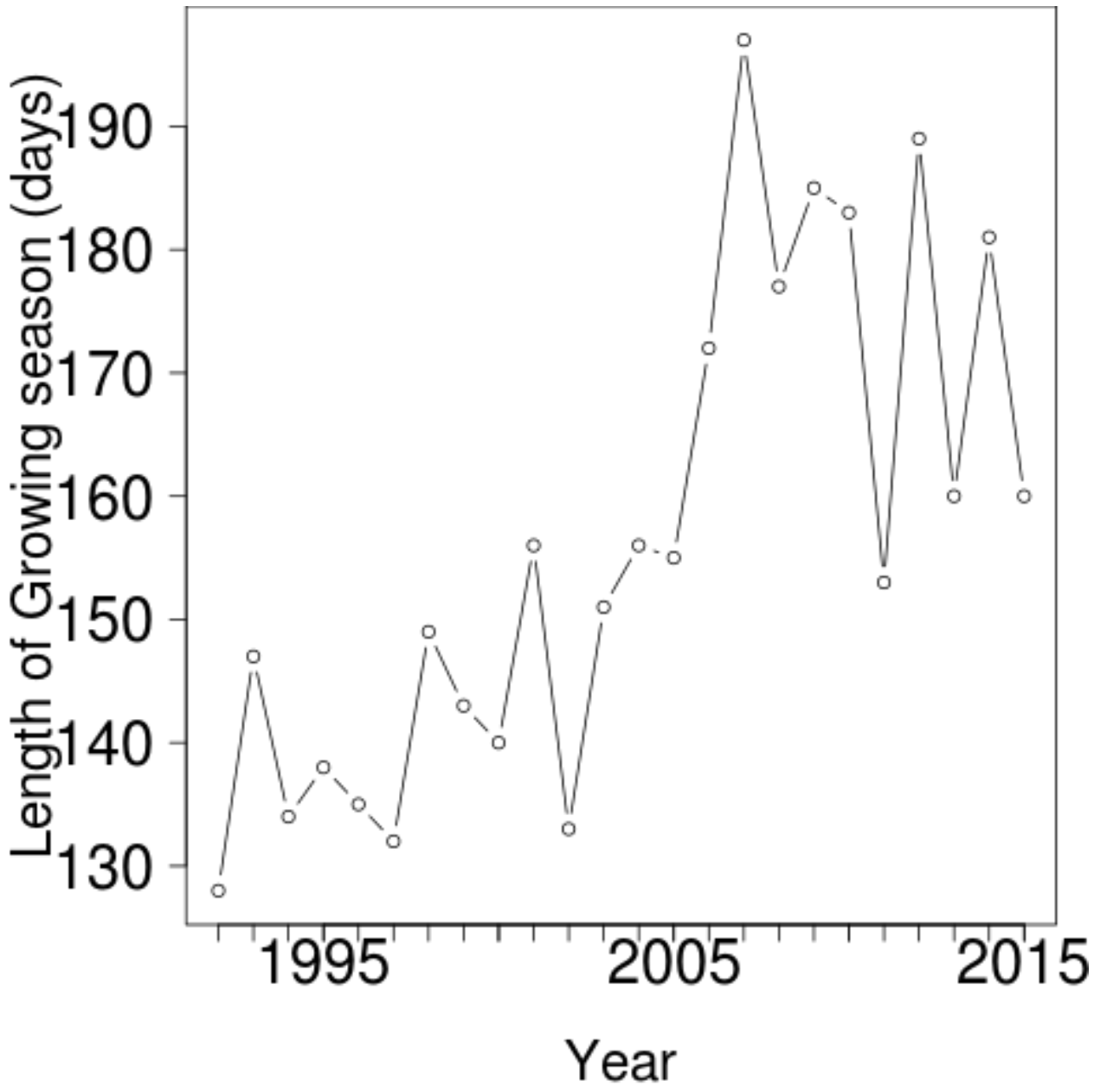
Timing of canopy development varies by a few weeks.

The range for peak LAI is about $1 m^2 m^{-2}$

There is some weak correspondence between density of foliage and magnitude of NEE

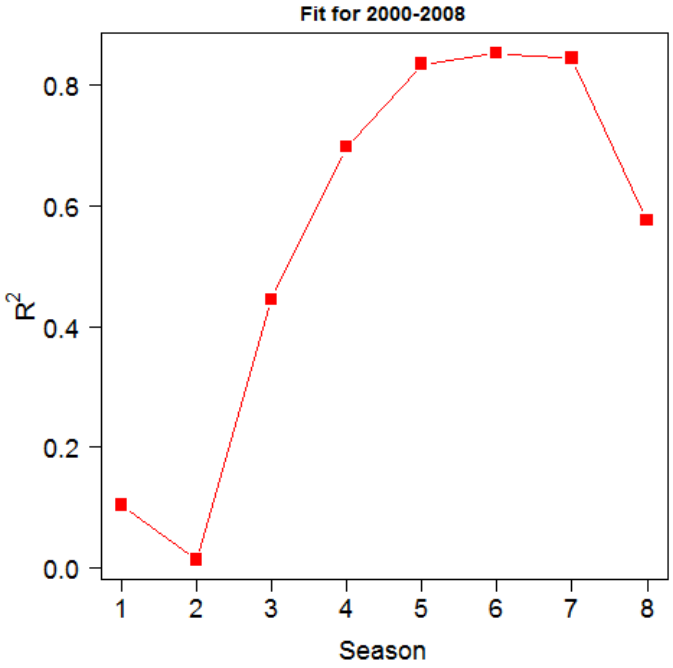


The most extreme extensions of carbon uptake season are outside the period that deciduous canopy is present

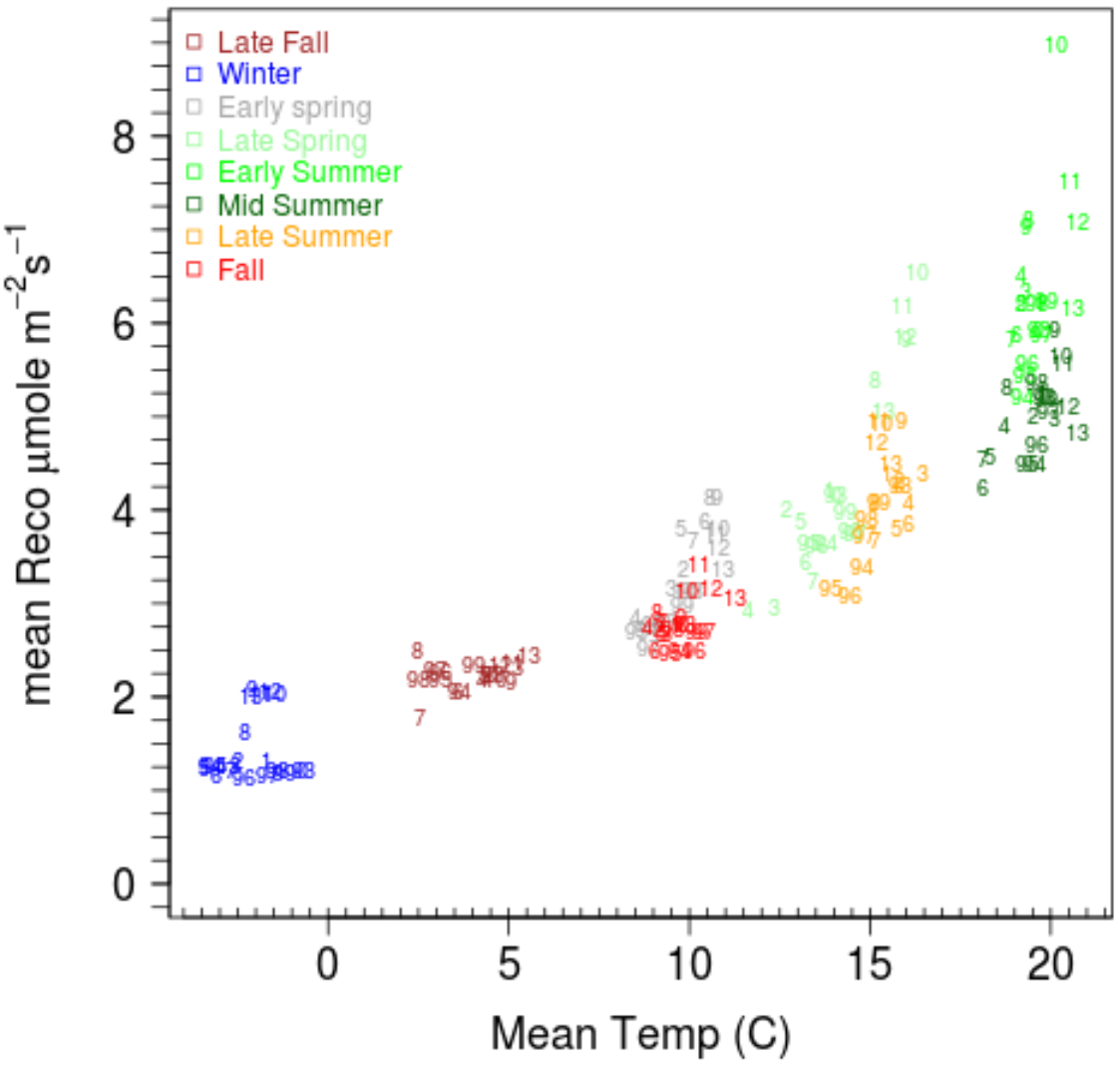

Length of Growing season (days)
130
140
150
160
170
180
190
1995
2005
2015
Year

Use a simple empirical fit to capture the temperature and light dependence of NEE for phenology-based seasonal periods.
Fit multiple years to obtain mean parameters and examine residuals to quantify anomalies or detect shifts in ecosystem function

$$NEE_{obs} = R_0 + a_2(T - \overline{T}) + \frac{(a_3 \times PAR)}{(a_4 + PAR)}$$



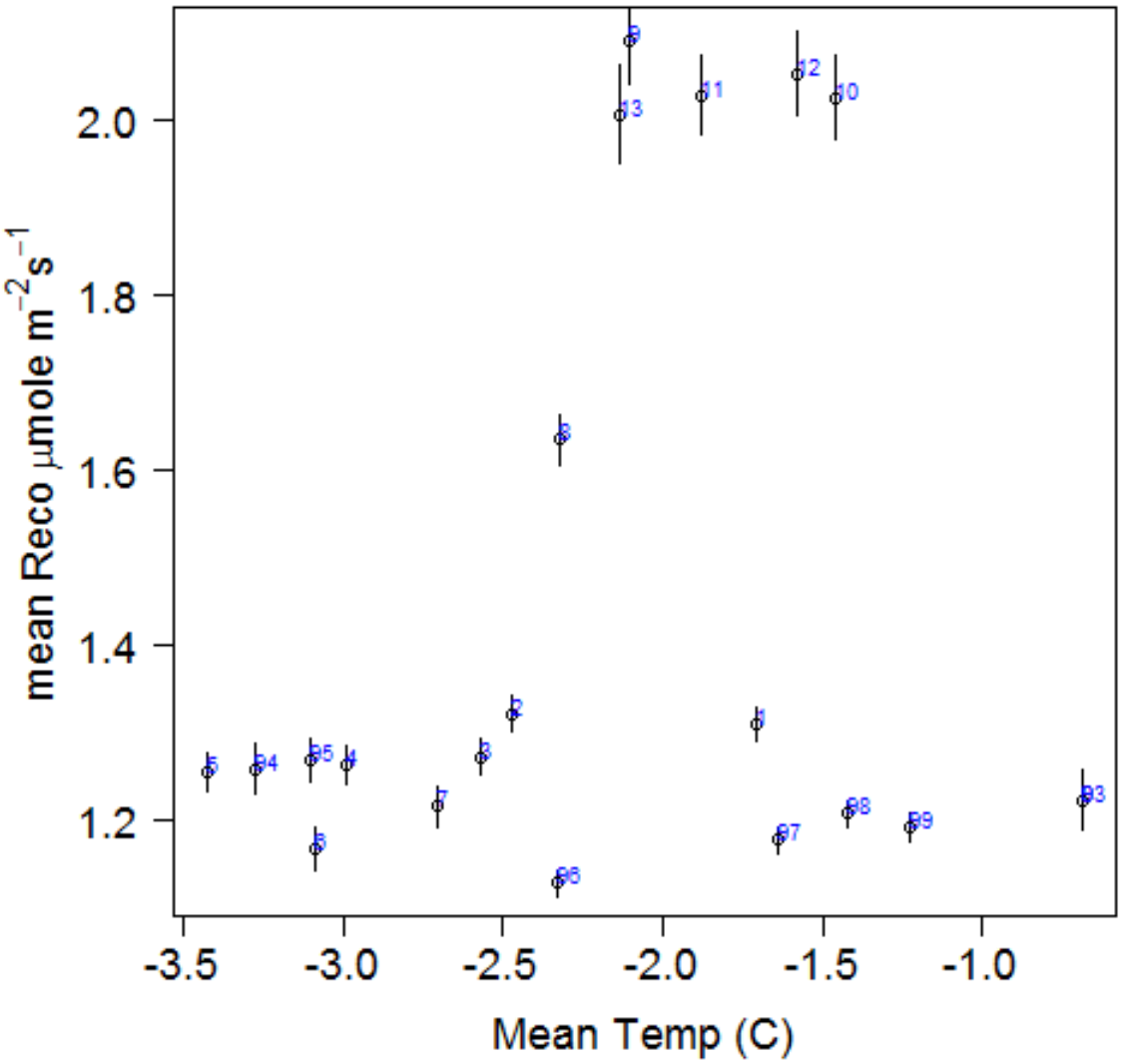
- Simple, low-order empirical fit represents the hourly variability during active growing season very well.
- Sets a baseline that process-models should exceed.
- Mean behavior is represented outside the growing season, but short-term variability is dependent on other factors.
- Model is not skilled at interannual patterns because (among others) shifts in carbon allocation and contribution from Carbon pools with multi-year lifetimes is not represented.



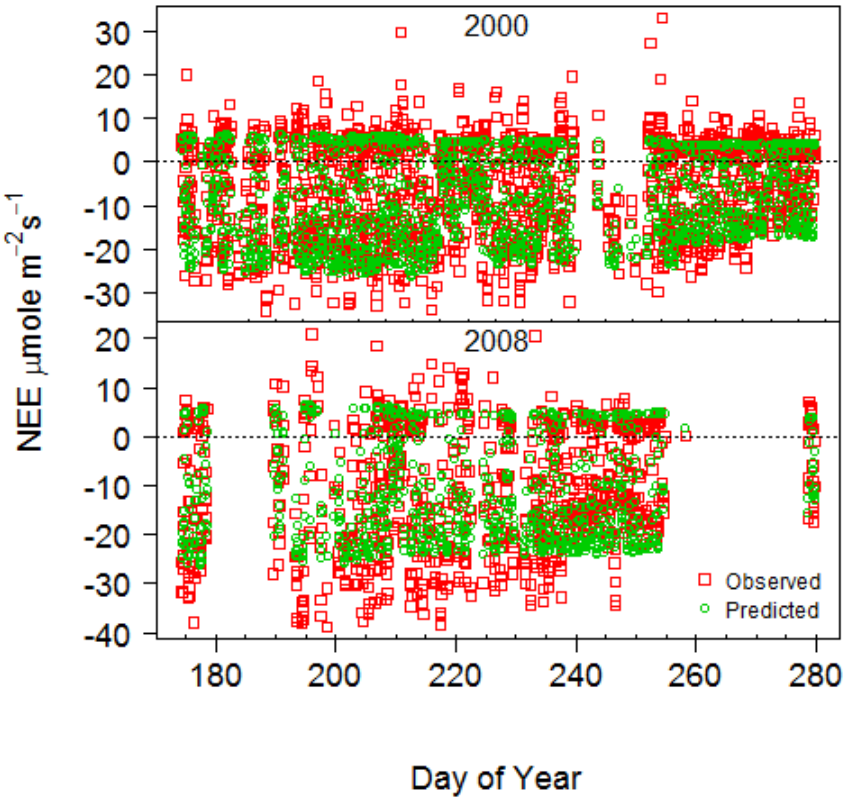
Mean respiration within seasons clearly separate along the axis for mean temperature. Apparent temperature response of mean respiration between different years having different mean temperature goes from fairly week in winter dormant to being non-physiologically steep for growing season.

For a given temperature range, respiration is higher in the early season (spring > fall), suggesting growth respiration for canopy development and root growth makes a large contribution.

Winter respiration exhibits two modes. Will be exploring role of snowpack.



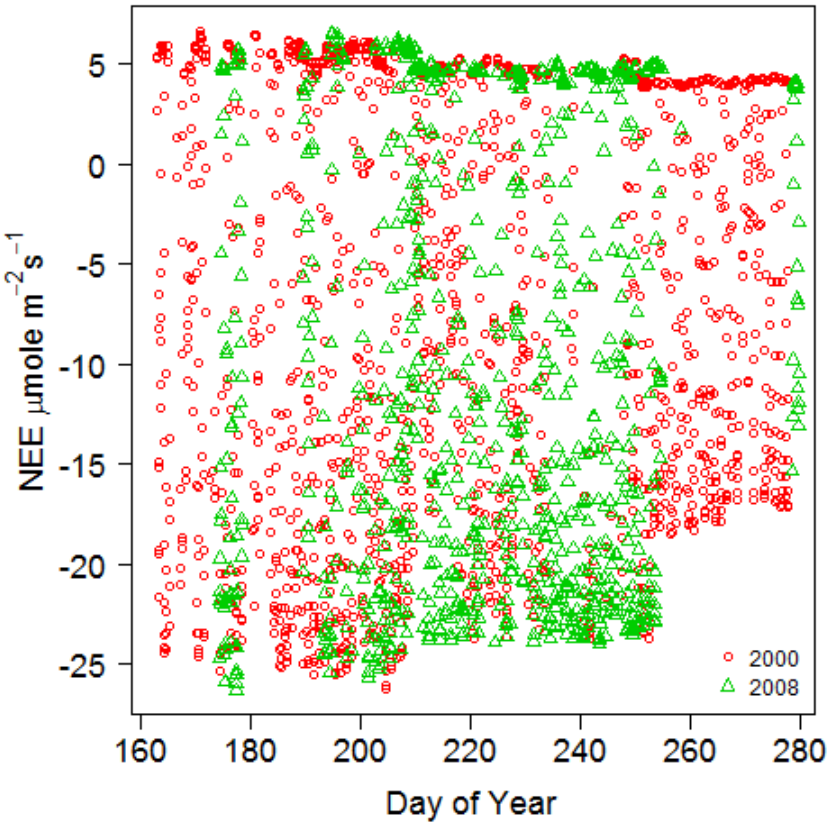
Dormant season mean ecosystem Respiration is temperature independent
Elevated ecosystem respiration events observed during a few years results in higher values for Mean Reco in any of the 5-year blocks including that year.
Suspect that the high Reco may be unrepresentative of the overall ecosystem.



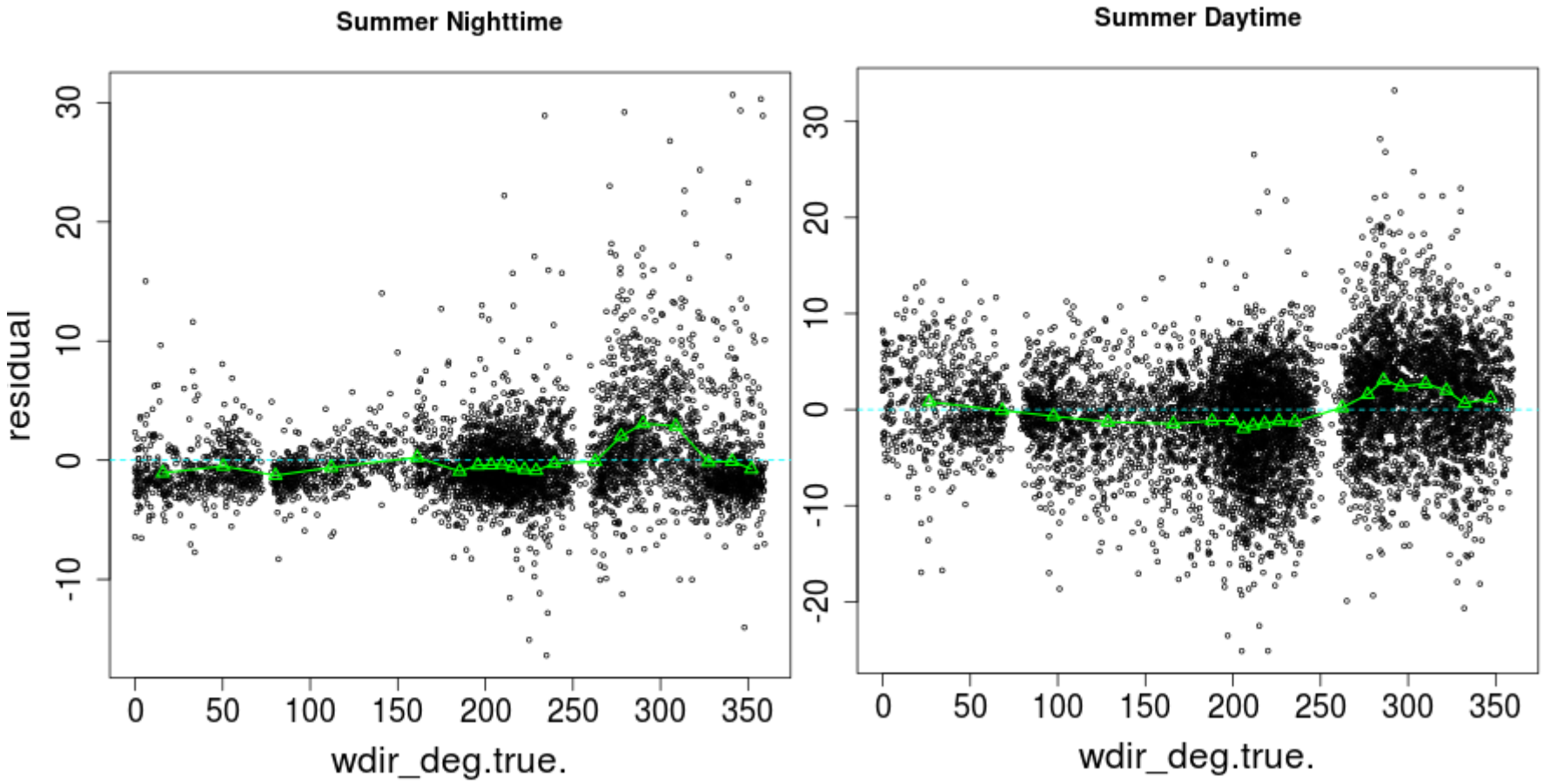
Observed NEE in 2008 exceeds prediction based on mean response and actual weather

Similar NEE values are predicted for both 2000 and 2008.

Enhanced NEE in 2008 is not driven by weather difference



With enough data, directional (species composition) differences can be detected



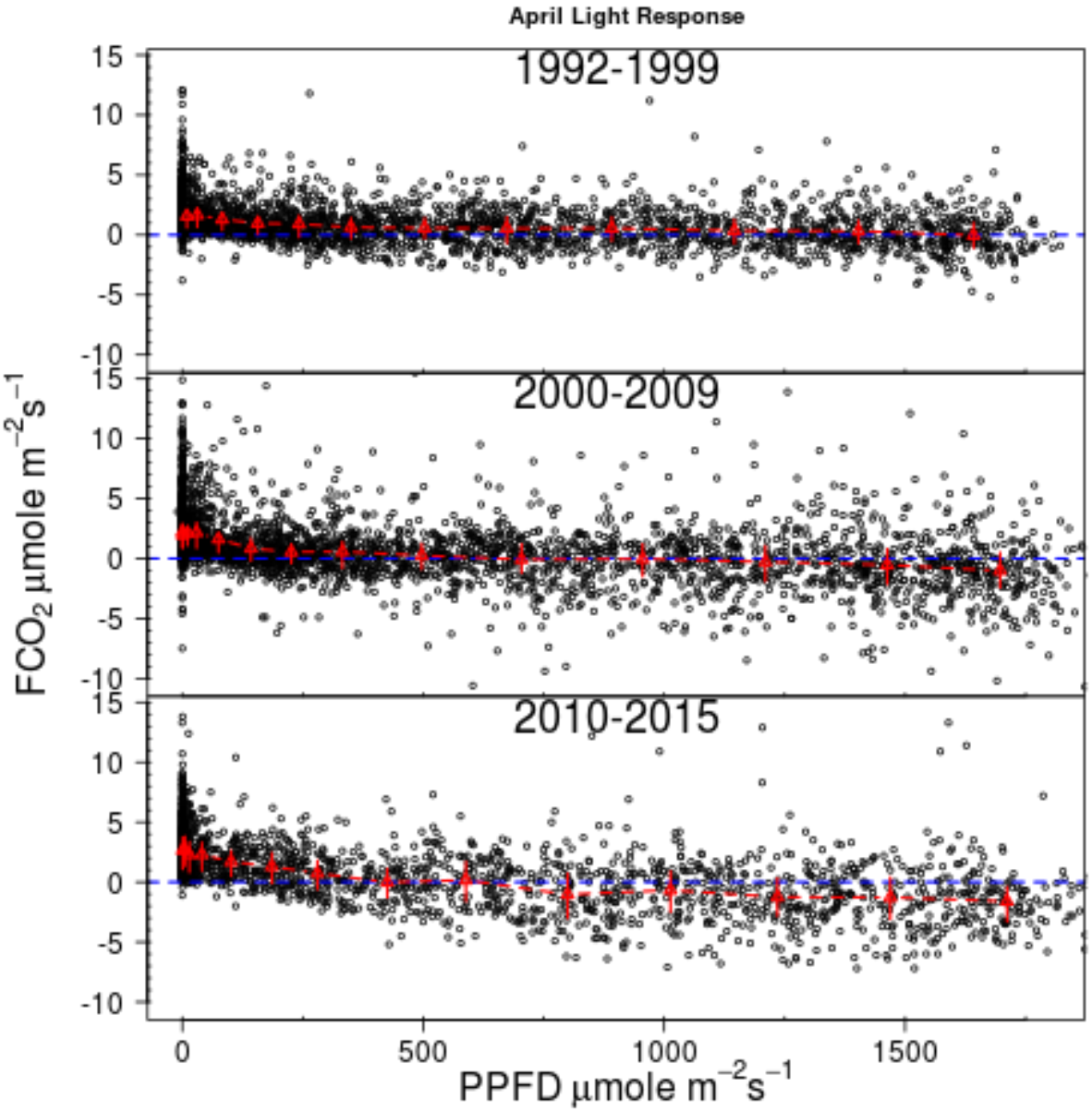
For the period 2000-2008 **observed NEE** in the NW sector **is more positive** than the value predicted by mean responses;
Influence of wetland and higher biomass of hemlock

Species matter

Slowly developing hemlock understory is contributing to shoulder season carbon fluxes

However, an invasive insect pest is decimating the hemlocks across eastern US and will kill both canopy dominant and understory individuals.

Decline is already being observed at Hemlock tower

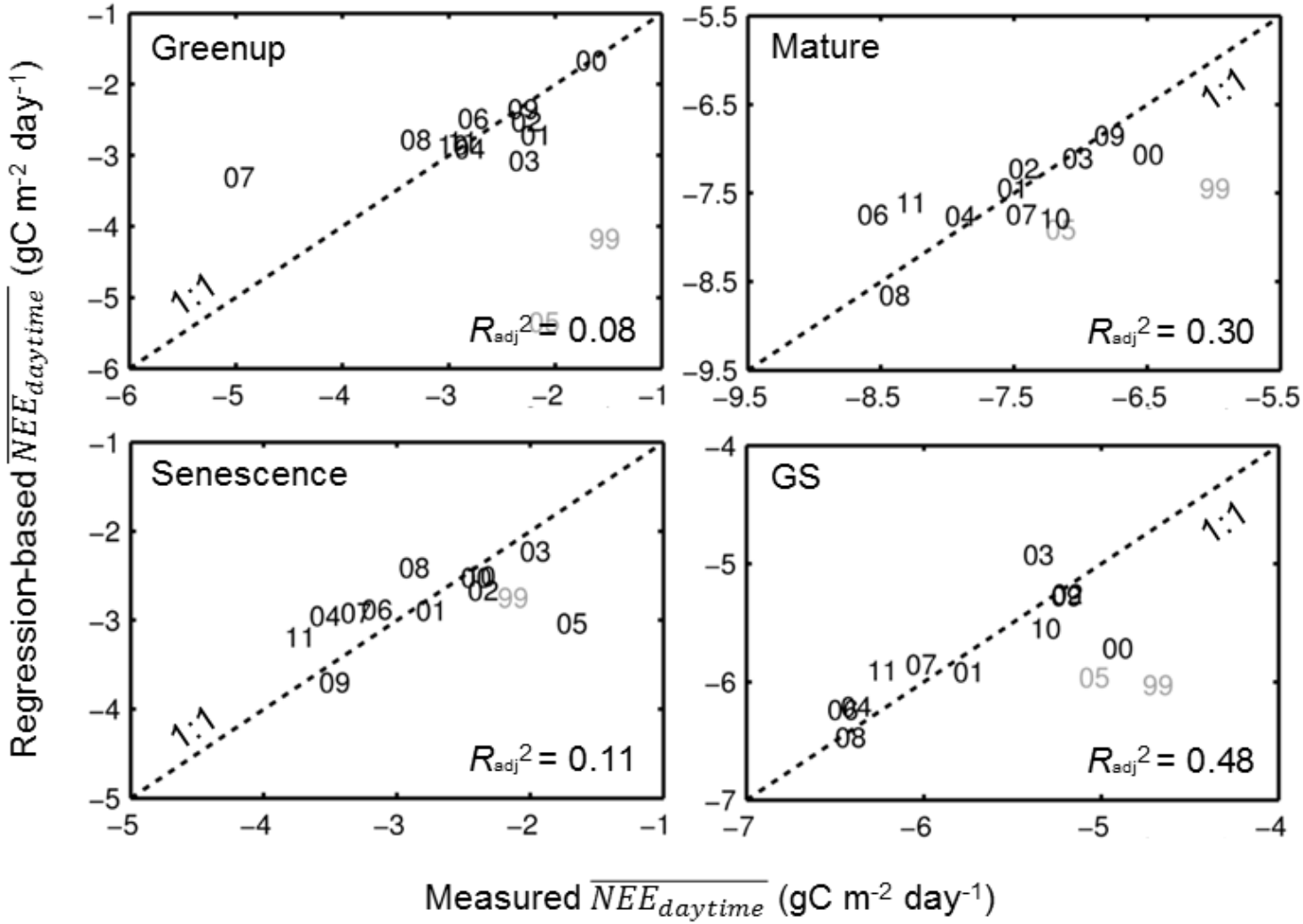


CO_2 flux during the month of April shows a tendency on decadal scales toward increase light dependency.

The forest is becoming photosynthetically active earlier due to warmer temperature combined with increased biomass of subcanopy hemlock saplings.

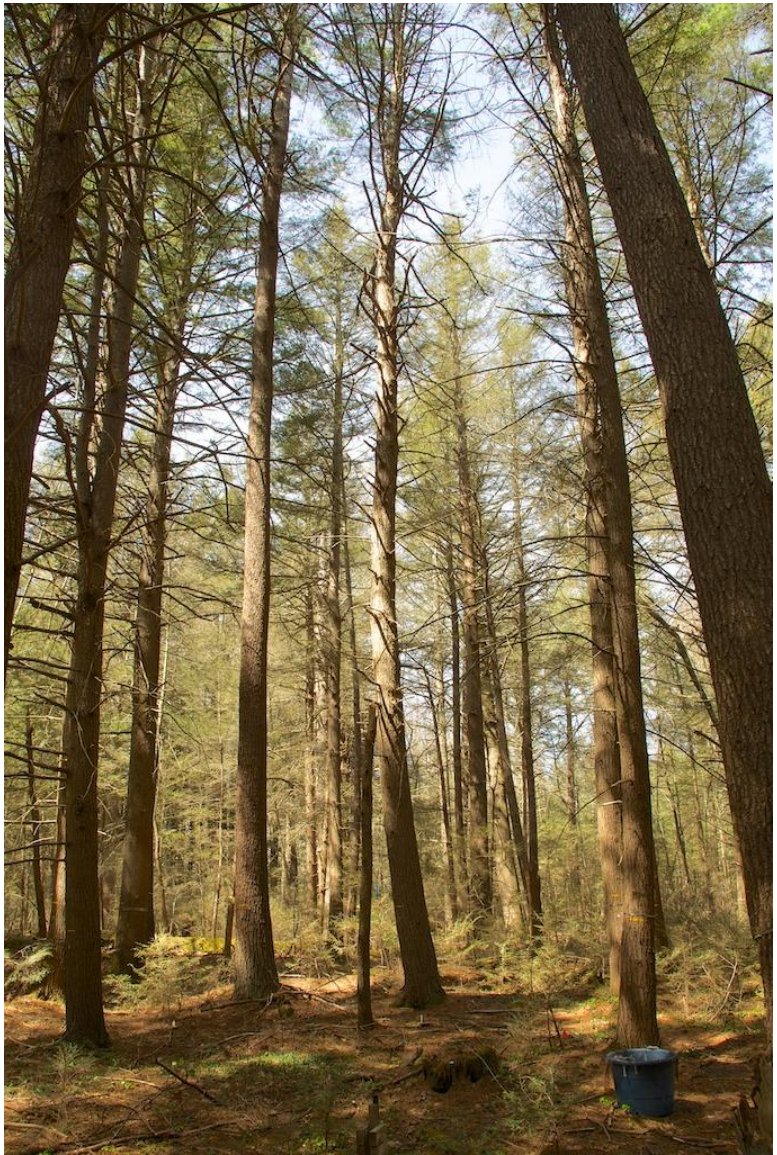

Harvard Forest Below Canopy PhenoCam Sat Apr 18 12:01:46 2009
Exposure: 335 Camera Temp 43.0 °C


Harvard Forest Below Canopy PhenoCam Sat Apr 22 08:01:43 2017 EST
Exposure: 2000 Camera Temp 32.5 °C

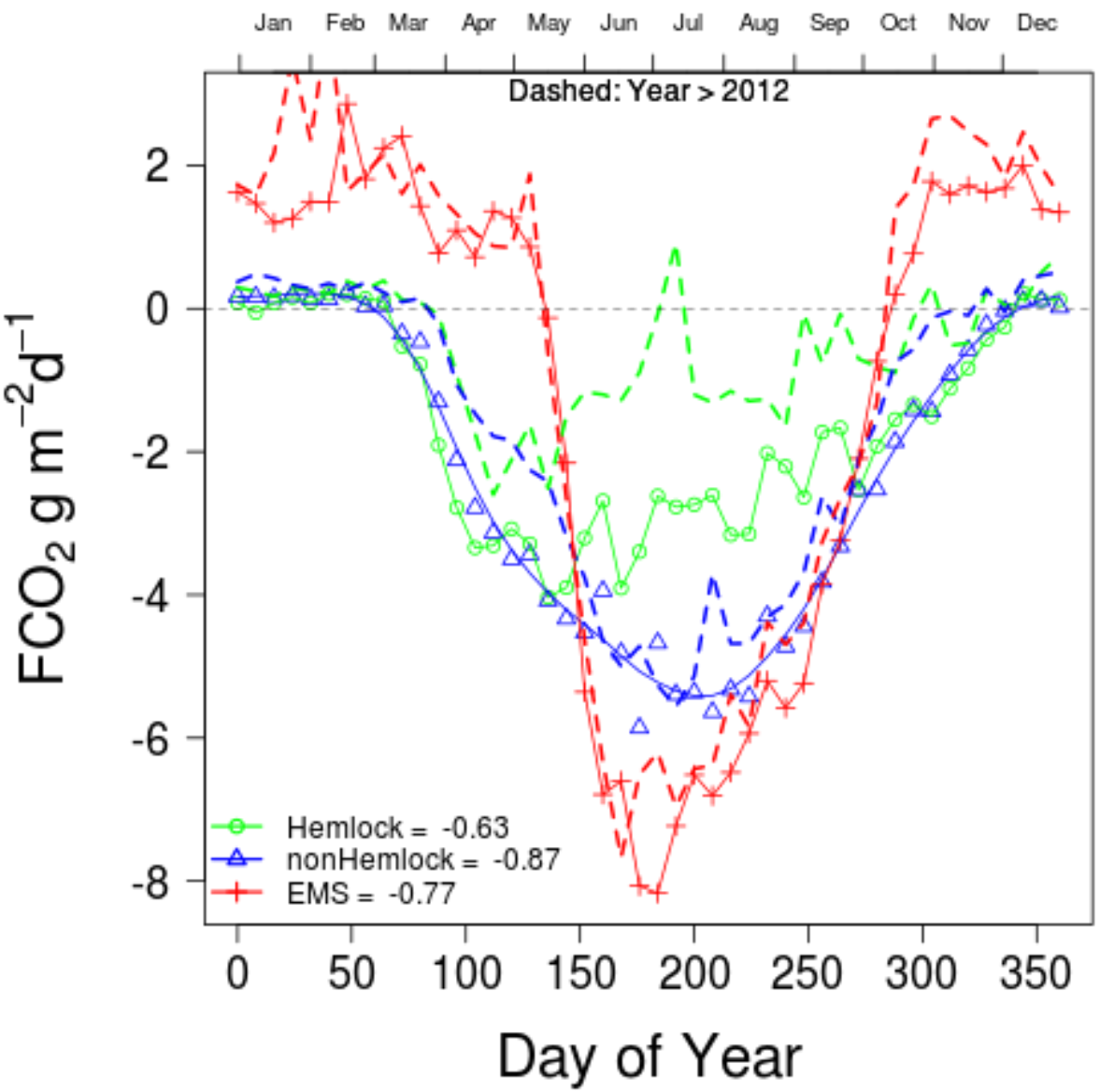


A regression based proportion of forest-cover type in the flux footprint accounts for some of interannual variability in growing season NEE
From (Kim etal. 2017 in review)

NEE response to HWA infestation

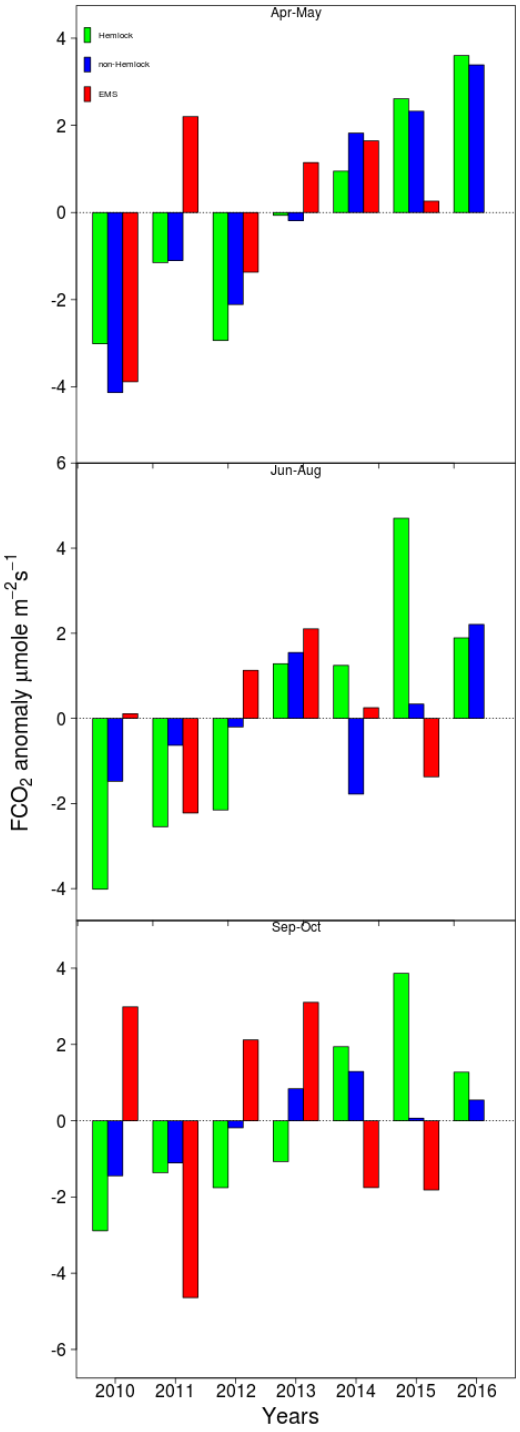


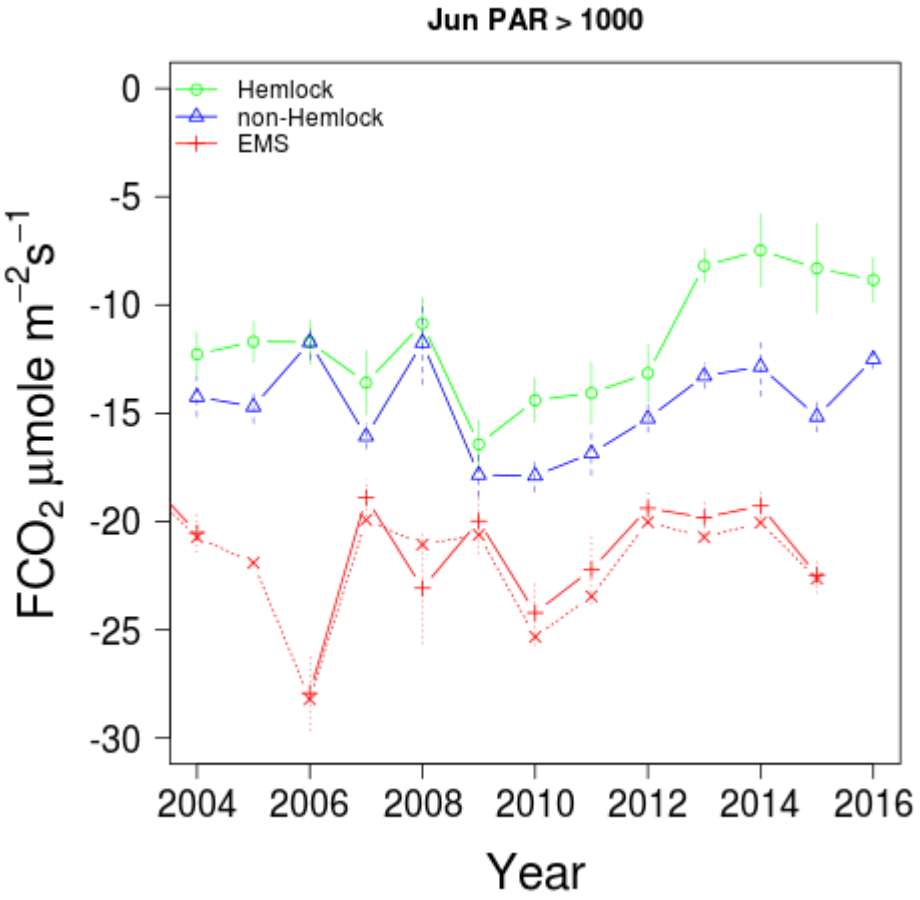
Crown progressively thins until tree ultimately dies.
Black birch sprouts in the sunlit gaps.



Average CO_2 fluxes for Hemlock tower in and out of hemlock sector and at EMS (control site)

For the directions dominated by hemlock the mid-summer mean CO_2 flux has declined by nearly 50% in magnitude. No corresponding decline for non-hemlock footprints.





Mean CO_2 flux at high light is declining

Anomaly computed as the difference in observed fluxes compared to baseline before appearance of HWA is 2-4 µmole m^{-2} s^{-1} more positive.

Summary

- Flux observations at the Harvard Forest (representative of temperate mixed forests in eastern North America) show consistent carbon uptake in undisturbed deciduous and conifer dominated stands.
- Photosynthesis and Respiration response to temperature can be fit well to NEE data, but interannual variation needs additional constraints to account for differences in allocation and response by slow-turnover carbon pools.
- Climate induced anomalies are observed to reduce uptake, but the forest recovers quickly (a few years).
- Mean functional response provides a baseline for quantifying relative contribution from direct response to weather and shifts in ecosystem function.
- Pest disturbance is reducing carbon uptake in conifer stand.
    - *Ongoing measurements will track the carbon balance as stand is replaced by deciduous species*