Diagnosing Sources of Temporal Variability in CO_2 Net Ecosystem Exchange at the Harvard Forest; What do 20 Years of Data Tell us?

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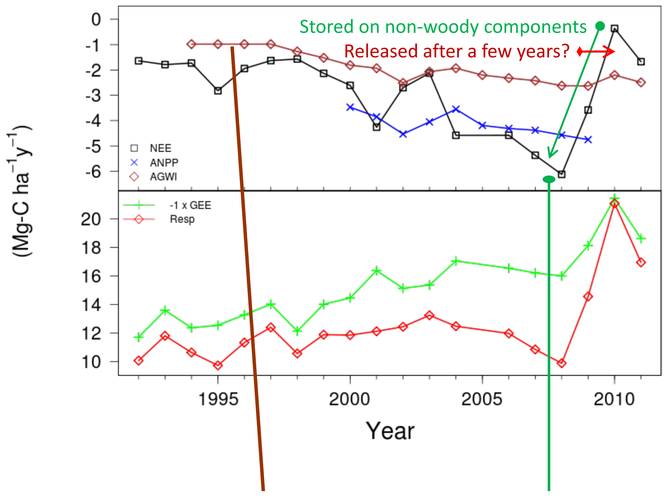
ABSTRACT

The Harvard Forest EMS flux tower has over 20 years of consistently-measured NEE and associated meteorological and biological data. In that time the forest has added over 20 Mg-C ha^{-1} in tree biomass while mortality and recruitment have been slowly shifting the canopy structure and species distribution. Mean annual temperature has increased more than 0.6C, which is 25% of the interannual variability. Temperature, light, and seasonality drive much of the variability, and for the most part these responses are well understood. A range of modeling approaches from simple regression fits of temperature and light response functions to detailed process-based ecosystem models all do a reasonable job of simulating the variability in NEE at hourly to daily scales, with R^2 better than 0.8 for most models. When fluxes are integrated to seasonal, annual, and longer intervals the emergent patterns are not well predicted by climate drivers and current understanding of ecosystem processes.

Spring and fall temperatures clearly influence both the timing of budburst and development of fall color as well as length of the active growing season at this site. The growing season as defined by net carbon uptake, is longer than the period that deciduous leaves are green, which demonstrating that conifers are important even though they are a small fraction of the biomass. One of the dominant features in the NEE time series has been a decade long period of increasing annual carbon uptake. Recent data show a reduced annual carbon uptake; whether this is a short pause or end of the trend can't be known yet. The overall message from this long-term observation is that short-term processes (e.g. photosynthesis) are fairly well understood, but our ability to predict future carbon storage depends on improved understanding of carbon allocation and particularly the fate of carbon pools with intermediate lifetimes.



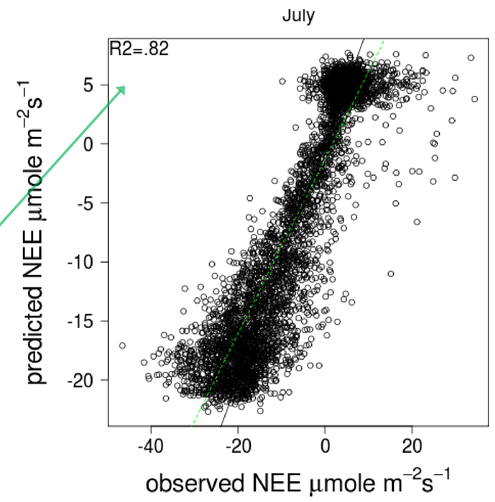
$$\mathrm{NEE} = R_{mn} + a_2 \times (\mathrm{T} - T_{mn}) + \left(\frac{a_3 \times \mathrm{PAR}}{a_4 + \mathrm{PAR}}\right)$$

Mean ecosystem function defined by fitting hourly NEE data to Temperature and light. NEE is predicted from the mean parameters and observed meteorology *(Urbanski et al., 2007)*.

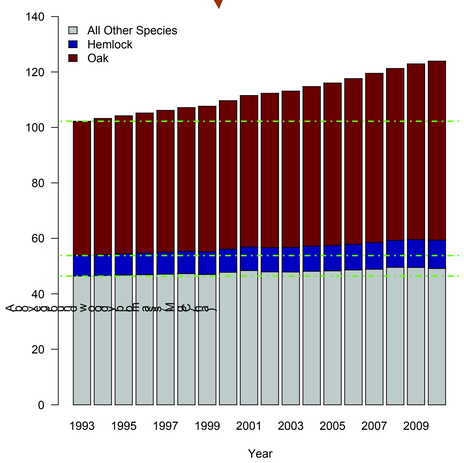
FoBAAR is a data-optimized ecosystem model (*Keenan et al., 2012*)

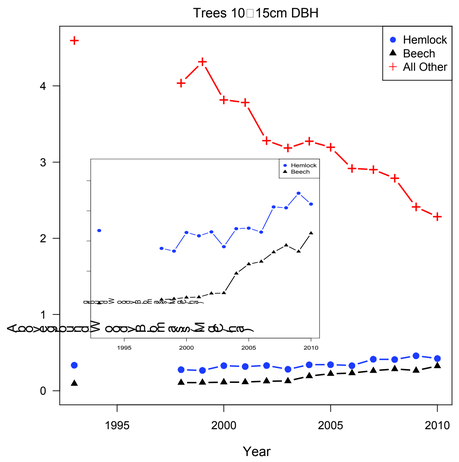
This simple statistical model captures most of the variance during the growing season (e.g. all of July data),

BUT predicted annual sums predicted do not track the observed annual sums

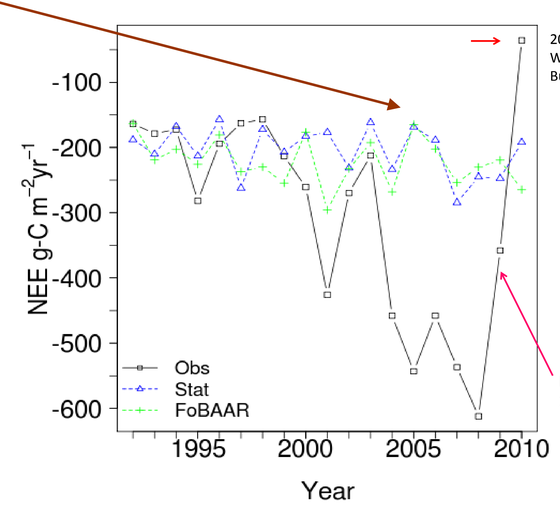


Above ground wood growth is dominated by red oak, Red maple, which is most of the 'other' species is barely growing

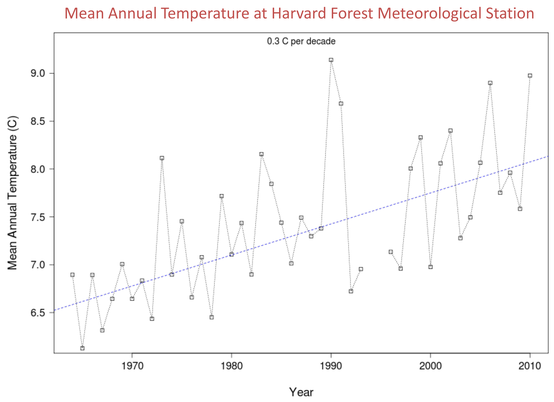


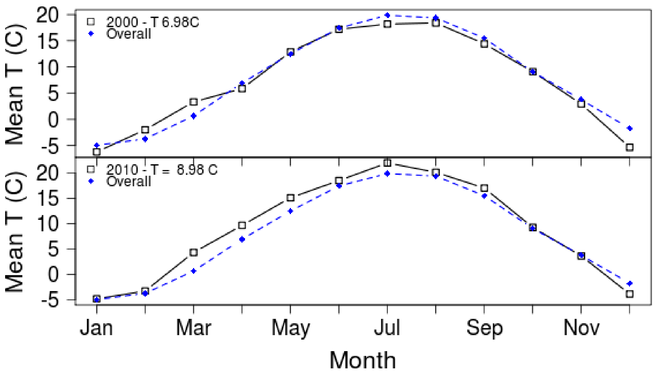


Small trees growing into the >= 10cm range are mostly beech and Hemlock

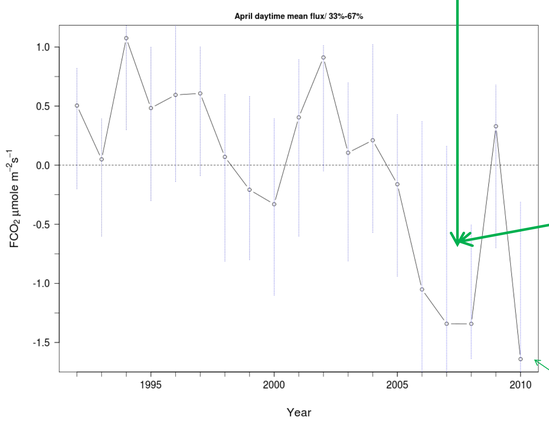


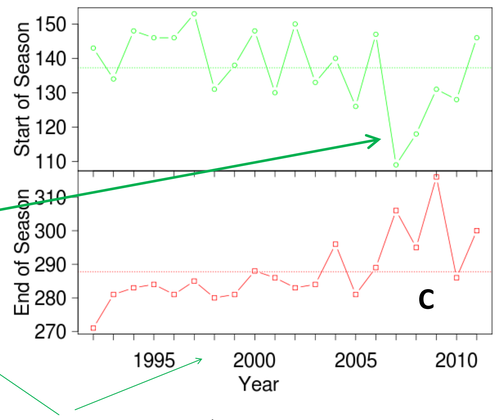
Temperature is Warming in Massachusetts though interannual variability exceeds decadal trend

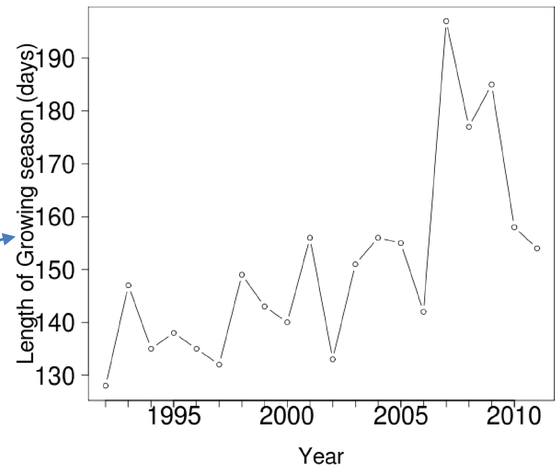




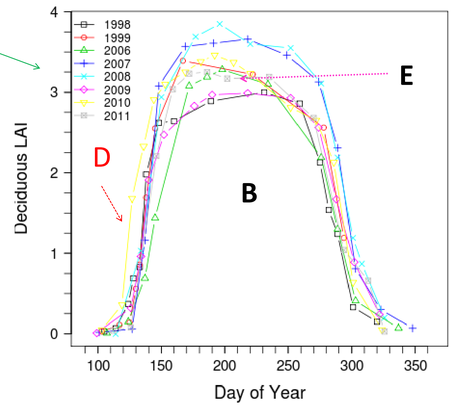
Shifts in Mean annual Temperature are made up from different patterns of monthly temperature anomalies





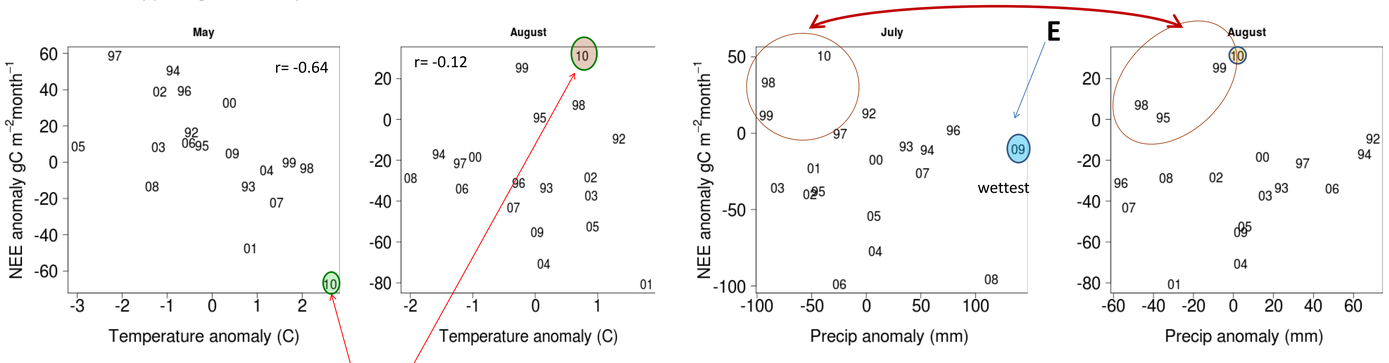


A



NEE anomaly (observed – predicted*) compared to weather anomaly (observed – 20 yr mean)

* See upper right for NEE prediction



D

Fast start in 2010 due to warm spring undone by hot summer and dry July

Cumulative dry July-August (98,99,10) lead to reduced Net Ecosystem Exchange

Key factors

- Early onset of growing season by conifer elements before full canopy development (A)
- Year to year variability in pace of canopy development and peak LAI is sensitive to spring weather and affected by winter disturbance (low LAI in 2009 from December 2008 ice storm) **(B)**
- Longer growing season in fall (long season enhances NEE, or high NEE allows season to extend?) **(C)**
- NEE responses to weather anomalies can be offset by subsequent events (Early uptake warm spring 2010 was set back by cold snap in May- **(D)**
- Cloudy wet June 2009 exacerbated canopy reduction from ice storm) **(E)**

References

Keenan, T. F., et al. (2012), Using Model-Data Fusion to Interpret Past Trends, and Quantify Uncertainties in Future Projections, of Terrestrial Ecosystem Carbon Cycling, *Global Change Biology*, *18*(8), 2555-2569.

Urbanski, S., et al. (2007) Factors Controlling CO_2 Exchange at Harvard Forest on Hourly to Annual Time Scales, *J. Geophys Res.*, 112, G02020, doi:10.1029/2006JG000293.

Acknowledgements

The Harvard Forest EMS Flux tower is a part of the Harvard Forest LTER, and an AmeriFlux core site with support from the Office of Science (BER), U. S. Dept. of Energy. Undergraduate student participation is supported by NSF REU program.

This work represents the contributions of many investigators over the years.