Evaluating the Contribution of Climate Forcing and Forest Dynamics to Accelerating Carbon Sequestration by Forest Ecosystems in the Northeastern U.S.

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Executive Summary

The objective of this project was to continue the long-term record of carbon, water and energy exchange above the forest canopy at tower sites in the Harvard Forest. These measurements have been made at the Environmental Measurement Site (EMS) tower since 1992, and at the Hemlock Tower since 2000. Forests respond slowly to climate shifts and succession, thus very long records are needed to detect and understand change. Plot-based measurement of above-ground biomass increment, litter input, and leaf area were made to complement the atmospheric measurement of fluxes to and from the forest.

The EMS tower is dominated by a mix of red oak and red maple deciduous trees. The hemlock tower samples from hemlock-dominated stand. These towers bracket the range of typical vegetation composition for the region. Comparison of data between the sites shows contrasting ecosystem strategies and potential response to warmer climate. The evergreen hemlock stand is able to begin photosynthesizing as soon as the temperature warms in the spring and continues in the late fall until it is too cold. The conifer stands are able to capitalize on warmer temperatures that extend the frost-free season. The deciduous stand is not able to respond as quickly to warm temperatures in early spring and late autumn because it has to grow new leaves and cannot resume photosynthesizing once the leaves begin to senesce. Although hemlock has a lower peak photosynthetic capacity than the oak, reduced summer carbon gain by hemlock is partly offset by the 1.5 – 2 month longer growing season that starts earlier and ends later compared to the active season for deciduous stands. Despite different strategies the two stands are both accumulating carbon in live biomass at about the same rate.

From 2000 through 2008 the annual carbon uptake measured at the EMS tower had been increasing, but declined sharply in 2009 and 2010, before higher uptake returned in 2011. Carbon accumulation in woody biomass increased somewhat over that period, but did not keep up with the highest rates of carbon uptake, which suggests that excess carbon during that period may have accumulated in material, such as litter and fine roots in the deep forest floor layer, that is less stable.

Key findings from this work

Trends in annual NEE The annual carbon budget of the forest is of particular interest. We measure it from the atmospheric perspective by integrating the hourly CO_2 fluxes up to quantify the total amount of carbon that moves between the forest and atmosphere. Secondly, we make annual measurements of the growth of live trees along with recruitment of small trees and mortality to quantify the annual increment in above-ground woody biomass. Since 2000, the forest at the EMS tower has been accumulating carbon at an accelerating rate. Uptake declined sharply in 2009 and 2010, but recovered somewhat in 2011 (Figure 1) Carbon accumulation in woody biomass increased somewhat over that period, but did not keep up with the highest rates of carbon uptake, which suggests that excess carbon during that period may have accumulated in material, such as litter and fine roots in the deep forest floor layer, that is less stable.

Differences between species Comparison of data between EMS and hemlock tower shows contrasting ecosystem strategies and potential for response to warmer climate. Compared to the deciduous-dominated EMS stand, the onset of carbon uptake starts about a month earlier in the evergreen hemlock stand, as soon as the temperature warms, in the spring and extends about a month later in the fall until it is too cold (Figure 2a-c). The conifer stands are able to capitalize on warmer temperatures that extend the frost-free season. The deciduous stand is not able to respond as quickly to warm temperatures in early spring and late autumn because it has to grow new leaves and cannot resume photosynthesizing once the leaves begin to senesce. Although hemlock has a lower peak photosynthetic capacity than the oak, reduced summer carbon gain by hemlock is partly offset by the 1.5 – 2 month longer growing season that starts earlier and ends later compared to the active season for deciduous stands. Despite different strategies the two stands are both accumulating carbon in live biomass at about the same rate (Figure 3).

Activity Summary

The main goals for the Harvard Forest site during this period were to maintain the continuity of core long-term flux and biometry measurements and perform as much ancillary measurements as practical within the scope of the project. One important accomplishment during the 2010-2012 period was to complete a significant upgrade of the data acquisition and control hardware that operates the EMS tower flux measurements. This system had been operating since 1989 and was becoming hard to maintain. New electronics were installed in April 2012 that improved reliability and allowed some expansion of data capacity. We continued the full schedule of tree diameter measurements, and multiple observation of leaf area index throughout the growing season. Fine woody debris surveys were completed in 2011 to follow up on the status of debris generated by an ice storm in winter of 2008-2009.

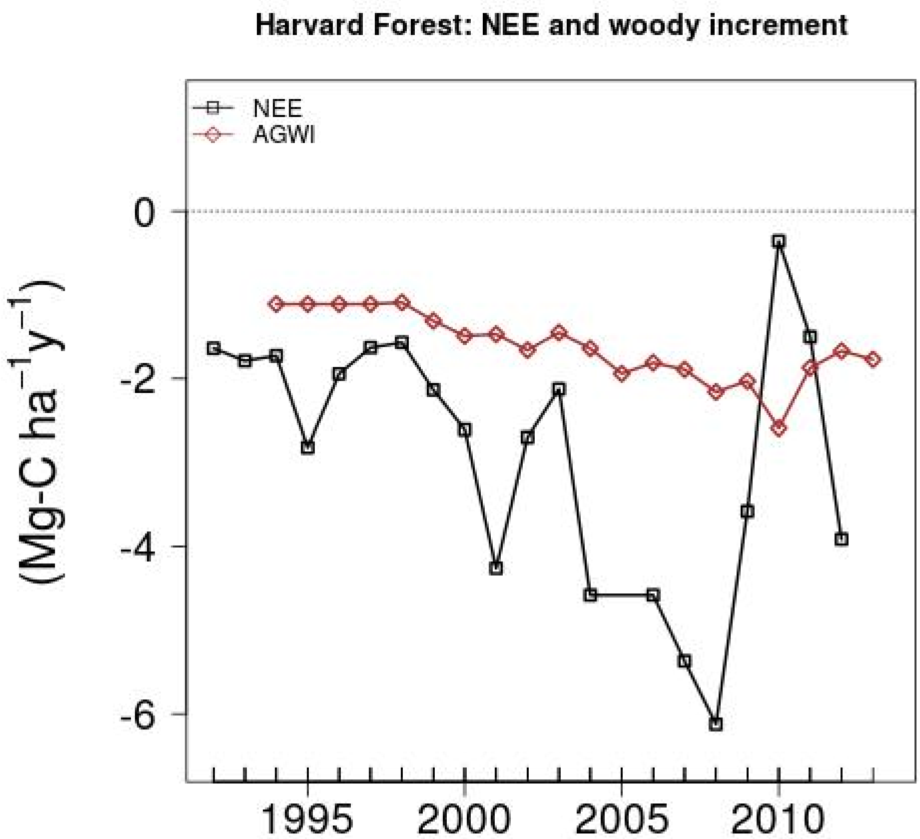

Figure 1 NEE and Above-ground Woody Incrment measured at the Harvard Forest EMS tower from 1992 through 2012.

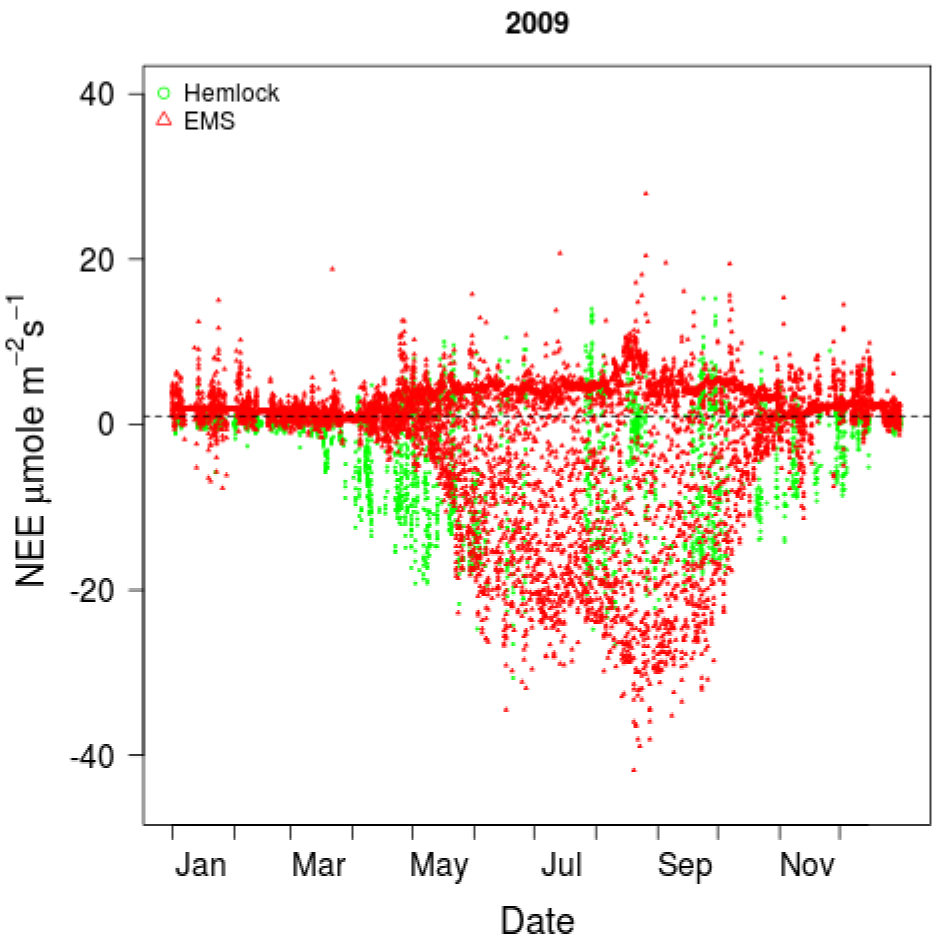

Figure 2a Hourly CO_2 fluxes at EMS and Hemlock tower in 2009. Notice that CO_2 uptake (negative fluxes) starts earlier in the spring at Hemlock than at EMS and extends later into the fall. The hemlock has weaker CO_2 uptake at its summer peak than the EMS site does.

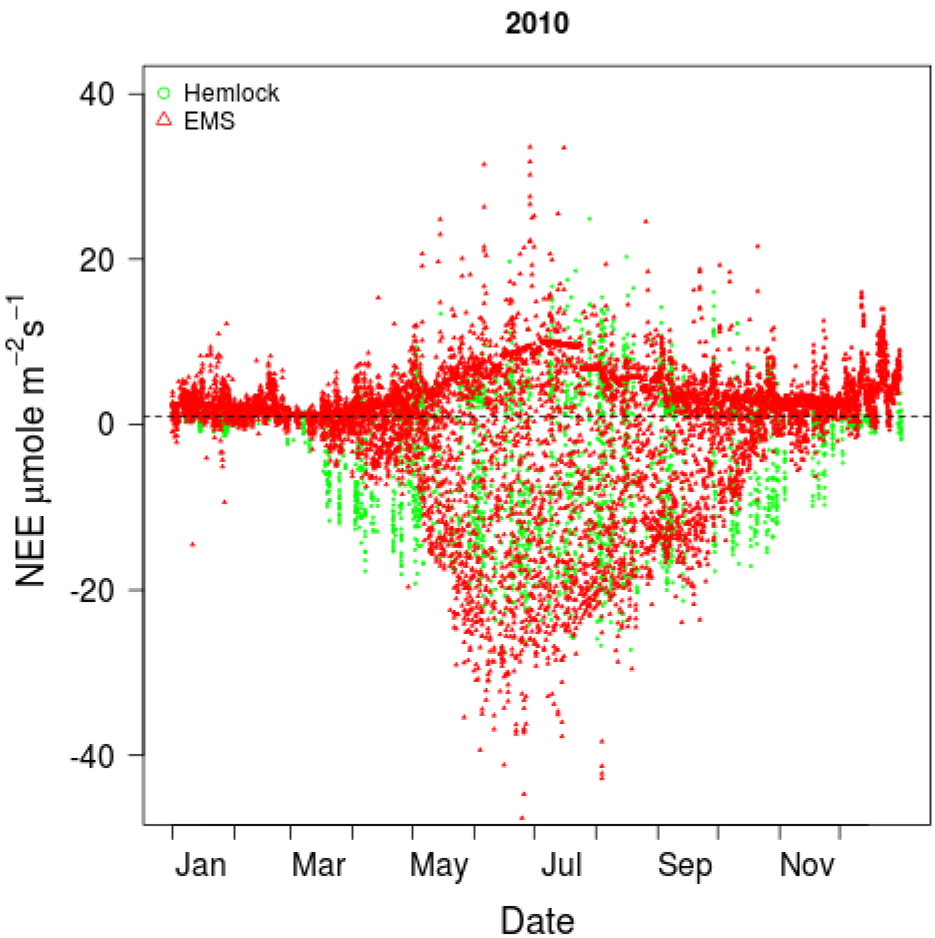

Figure 2b Hourly CO_2 fluxes at EMS and Hemlock tower in 2010

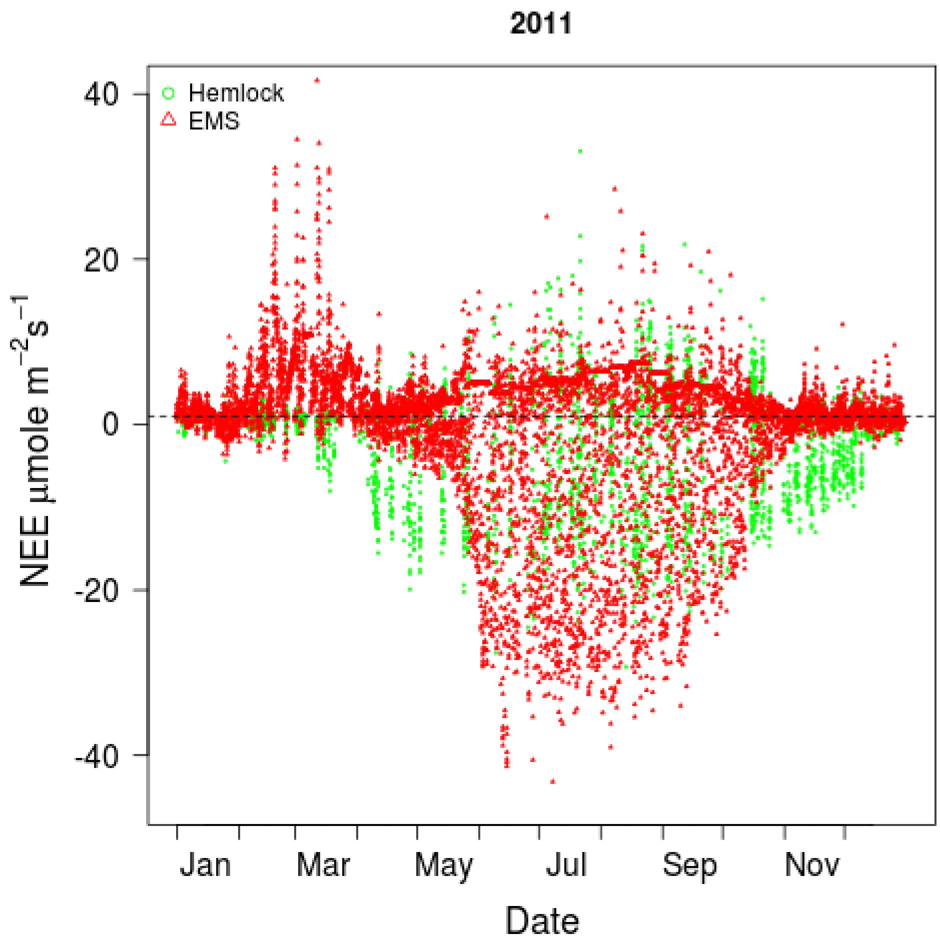

Figure 2c Hourly CO_2 fluxes at EMS and Hemlock tower in 2011. Very high respiration is observed at the EMS site during winter, which partially accounts for the reduced annual carbon uptake for the year.

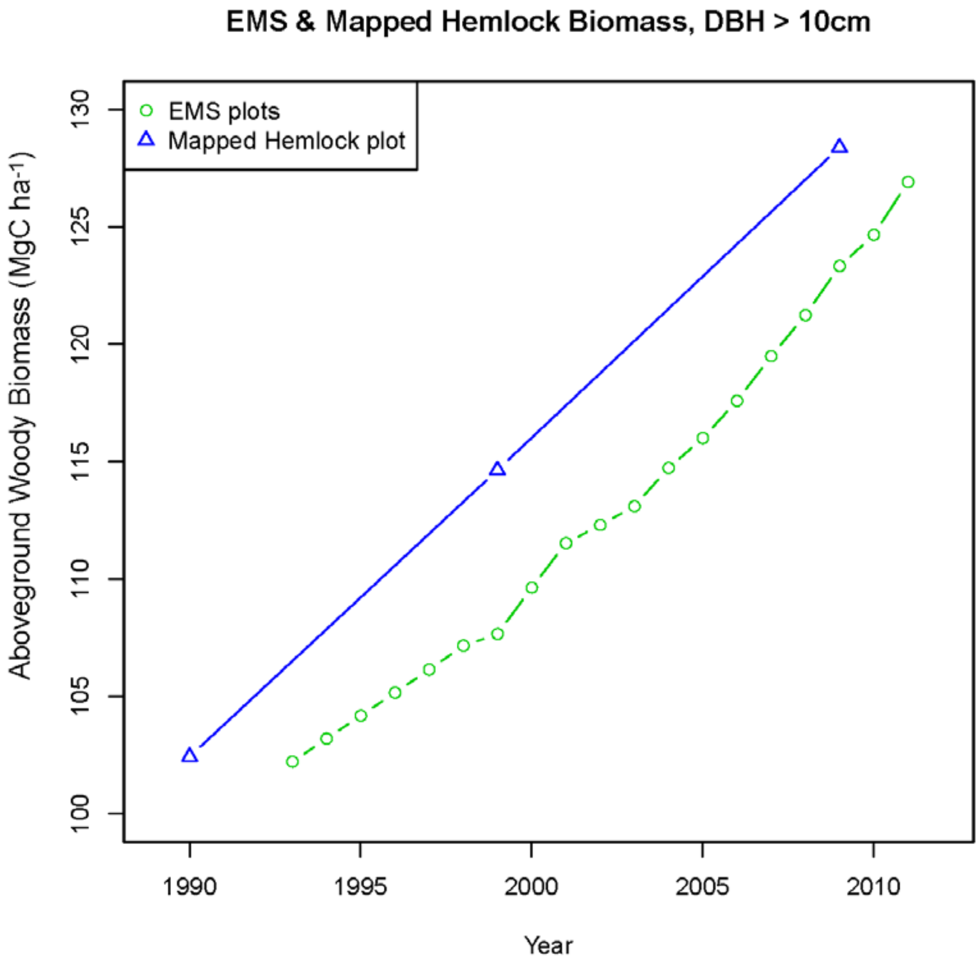

Figure 3 Above-ground woody biomass measured annually across the array of EMS biometry plots and at a plot near the hemlock tower that has been measured at decadal intervals. Annual measurements show more variability than is evident from measurements made at decadal intervals, but both stands have similar total carbon and nearly identical average carbon uptake over the long term.

Research products

Project data sets are posted to our in-house ftp servers as well as submitted to the AmeriFlux data server at Oak Ridge National Lab and made available as level 2-4 data files and biological data spreadsheets
http://public.ornl.gov/ameriflux/Site_Info/siteInfo.cfm?KEYID=us.harvard_forest.01
http://public.ornl.gov/ameriflux/Site_Info/siteInfo.cfm?KEYID=us.harvard_forest_hemlock.01

Data sets

1. Hourly fluxes of CO_2, H_2O, heat and momentum and estimated partitioning of NEE into the GEE and R_{eco} components, *available at;*
ftp://ftp.as.harvard.edu/pub/nigec/HU_Wofsy/hf_data/Final
ftp://ftp.as.harvard.edu/pub/nigec/HU_Wofsy/hf_data/Final/Filled
http://harvardforest.fas.harvard.edu:8080/exist/xquery/data.xq?id=hf103

2. Annual above-ground woody biomass increment, litter input, and above-ground mortality and total stocks of live above-ground biomass in large trees (dbh > 10 cm) and coarse and fine woody debris *available at;*
ftp://ftp.as.harvard.edu/pub/nigec/HU_Wofsy/hf_data/ecological_data/trees/
ftp://ftp.as.harvard.edu/pub/nigec/HU_Wofsy/hf_data/ecological_data/woody_debris
ftp://ftp.as.harvard.edu/pub/nigec/HU_Wofsy/hf_data/ecological_data/litter
http://harvardforest.fas.harvard.edu:8080/exist/xquery/data.xq?id=hf151
http://harvardforest.fas.harvard.edu:8080/exist/xquery/data.xq?id=hf149

3. Time series of LAI and canopy nitrogen over the growing season *available at*;
ftp://ftp.as.harvard.edu/pub/nigec/HU_Wofsy/hf_data/ecological_data/lai
ftp://ftp.as.harvard.edu/pub/nigec/HU_Wofsy/hf_data/ecological_data/leaf.chemistry/
http://harvardforest.fas.harvard.edu:8080/exist/xquery/data.xq?id=hf150

4. Surveys of understory vegetation near EMS tower *available at;*
ftp://ftp.as.harvard.edu/pub/nigec/HU_Wofsy/hf_data/ecological_data/trees/understory/

Publications (*including collaborations and synthesis participation)*

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Conference presentations

A Multi-Decadal Perspective On The Ecosystem Carbon Budget In A U.S Eastern Deciduous Forest: Results from the Harvard Forest, J. William Munger, Josh McLaren, Leland Werden, Steven Wofsy, presented at iLEAPS Science Conference, 18 - 23 September 2011, Garmisch-Partenkirchen, Germany

Net Carbon Exchange And Biomass Accumulation As A Function Of Species Composition And Stand Age At The Harvard Forest In Central Massachusetts, J. William Munger, Leland Werden, Julian. Hadley, David R. Foster, Audrey. Barker-Plotkin, and Steven. C. Wofsy, presented at American Meteorological Society, First Conference on Atmospheric Biogeosciences, Boston, MA, May 29 2012.

Identifying Signatures of Climatic Influence on Forest Net Carbon Exchange From 20 years of Observations at Harvard Forest, J William Munger, Steven C Wofsy, Jakob Lindaas, Trevor F. Keenan, presented at 2012, American Geophysical Union Fall Meeting, San Francisco, CA, December 3-7, 2012.