Carbon Dynamics of Natural Disturbance (Storms and Fire) in the Eastern U.S. Temperate Forests

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Abstract

Most temperate forests in the eastern U.S. are currently recovering from disturbance, most commonly human disturbances such as agricultural abandonment and timber harvest. The natural disturbances of fire and storms also have an impact. Fires were more prevalent before the1920s, and tropical storms and hurricanes are more prevalent along the coasts. We have constructed gridded datasets at the 0.5ºx0.5º resolution of tropical storm and hurricane return intervals based on the Zeng et al. (2009) data and fire rotations based on LANDFIRE Rapid Assessment Vegetation Models and vegetation types from Nowacki and Abrams (2008). These data are used within the TEM-Hydro model to determine the carbon dynamics of the temperate forest ecosystem by applying them both stochastically once within the last hundred years and by effecting an equivalent but annually applied disturbance spread out evenly over the century. Runs show decreases in vegetation carbon as a result of disturbance. Regrowth causes the NEP to increase with disturbance, but fails to offset the direct loss of carbon from the disturbances themselves.

Experiment	Fire	Storm	Annual	Stochastic
ND	No	No	N/A	N/A
FD	Yes	No	Yes	No
FDS	Yes	No	No	Yes
SD	No	Yes	Yes	No
SDS	No	Yes	No	Yes

Dataset Construction

Fire

The fire return data sets are based on vegetation type data from Nowaki and Abrams (2008). These polygon data of vegetation were converted into longitude/latitude grids of 0.5*x0.5* resolution using an inverse distance weighting. For each vegetation type, the USDA Forest Service Fire regime table was used to assign an average fire rotation. The fire rotation for an area represents the time it takes for the accumulation of fires to burn the equivalent of the entire area. Because of policy changes in the 1920s, the fire regimes of the eastern US have undergone significant changes, usually resulting in less fire. Apart from the change in 1920, the fire rotations remain static.

Storms

Storms were divided into two different categories: hurricanes and tropical storms, each with different degrees of damage and different return intervals. Data sets for the return intervals of tropical storms and hurricanes were obtained from Zeng et. al. (2009). The return interval for storms represents the approximate time in years between storms occurring in a particular grid. Kriging interpolation was used to transform the return interval data to the TEM grid (Fig. 1). The storm and hurricane intervals remain static.

Methods

New standing dead pools were added to represent the carbon and nitrogen held in trees that have died but not yet decomposed due to fires or storms (Fig. 2). The carbon and nitrogen in these pools are gradually converted to slash at a rate of 7% per year (Harmon 1982), with some of the carbon volatilized directly to the atmosphere. We also added the option of representing different types of disturbance, storms and fire as either stochastic, large recurrent events or, annual, small yearly events. Disturbances were applied for each grid in August.

Stochastic Storms:

A storm is simulated if the year corresponds to a multiple of the return interval. For instance, with a return interval of 100 years, storms would occur on years 100, 200, 300, etc…We assumed 27% destruction of leaves and 13.5% destruction of stems for a hurricane (Foster and Boose 1992). A tropical storm is assumed to have half the destruction of a hurricane (Francis and Gillespie 1993). The destroyed leaf, root and labile carbon are added to slash, while the sapwood and heartwood are added to the standing dead pool.

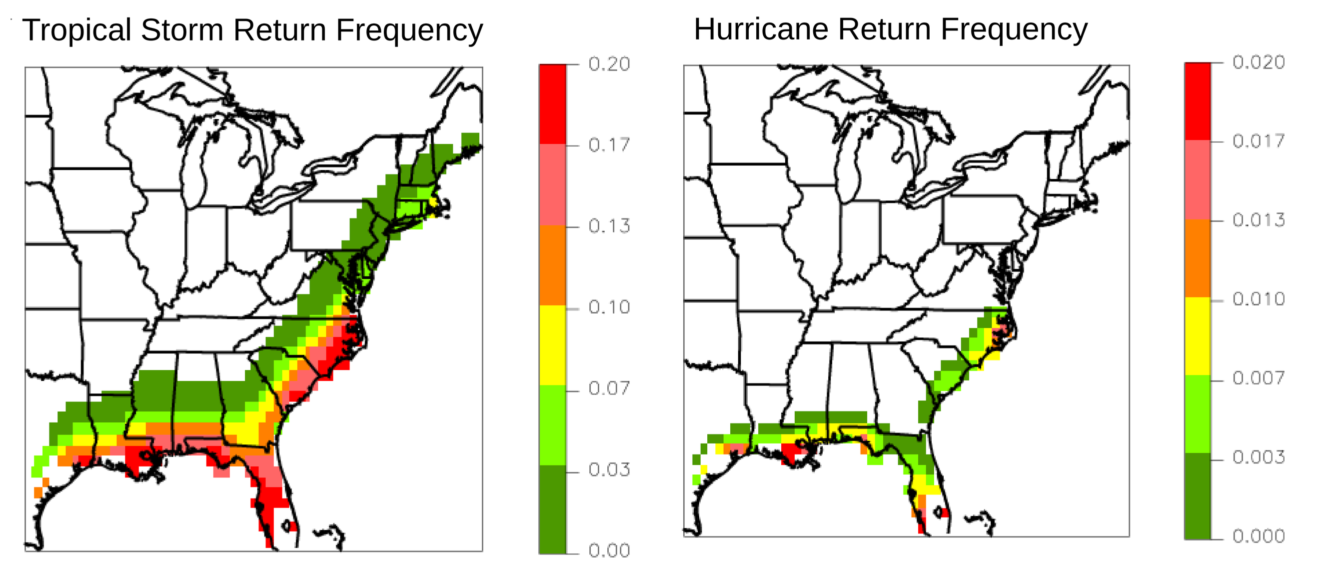


Figure 1.

Annual Storms:

We apply the same destruction percentages as stochastic storms. This percentage is multiplied by the reciprocal of the return interval. For example, a return interval of 100 would result in an annual destruction of 0.01 x (%destroyed). The destroyed vegetation is treated in the same way as stochastic storms.

Stochastic Fire:

The vegetation type is referenced against the USDA forest service fire regime table, which provides return intervals for low intensity, mid intensity and stand replacement intensity fires, causing 87.5%, 50% and 12.5% destruction, respectively. If fire occurs, the leaf and root carbon and nitrogen of burned trees are added directly to slash. The burned sapwood, heartwood and labile carbon each have 1/3 of their carbon and all of their nitrogen added to the standing dead pools, with the remaining carbon volatilized.

Annual Fire:

Either the past (fire prior to 1920) or present (fire after 1920) fire rotation data sets are referenced. The reciprocal of the rotation length is equal to the percentage of vegetation burned annually. For example a grid with a 100 year fire rotation would have 1% burned per year. The burned vegetation is treated identically as in stochastic fire.

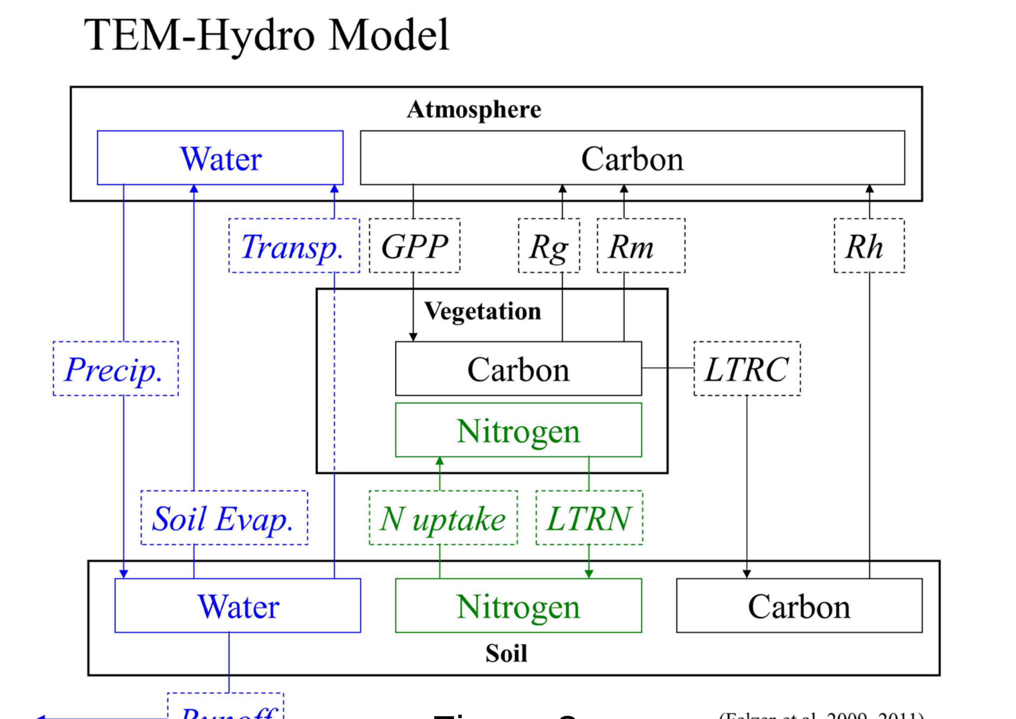
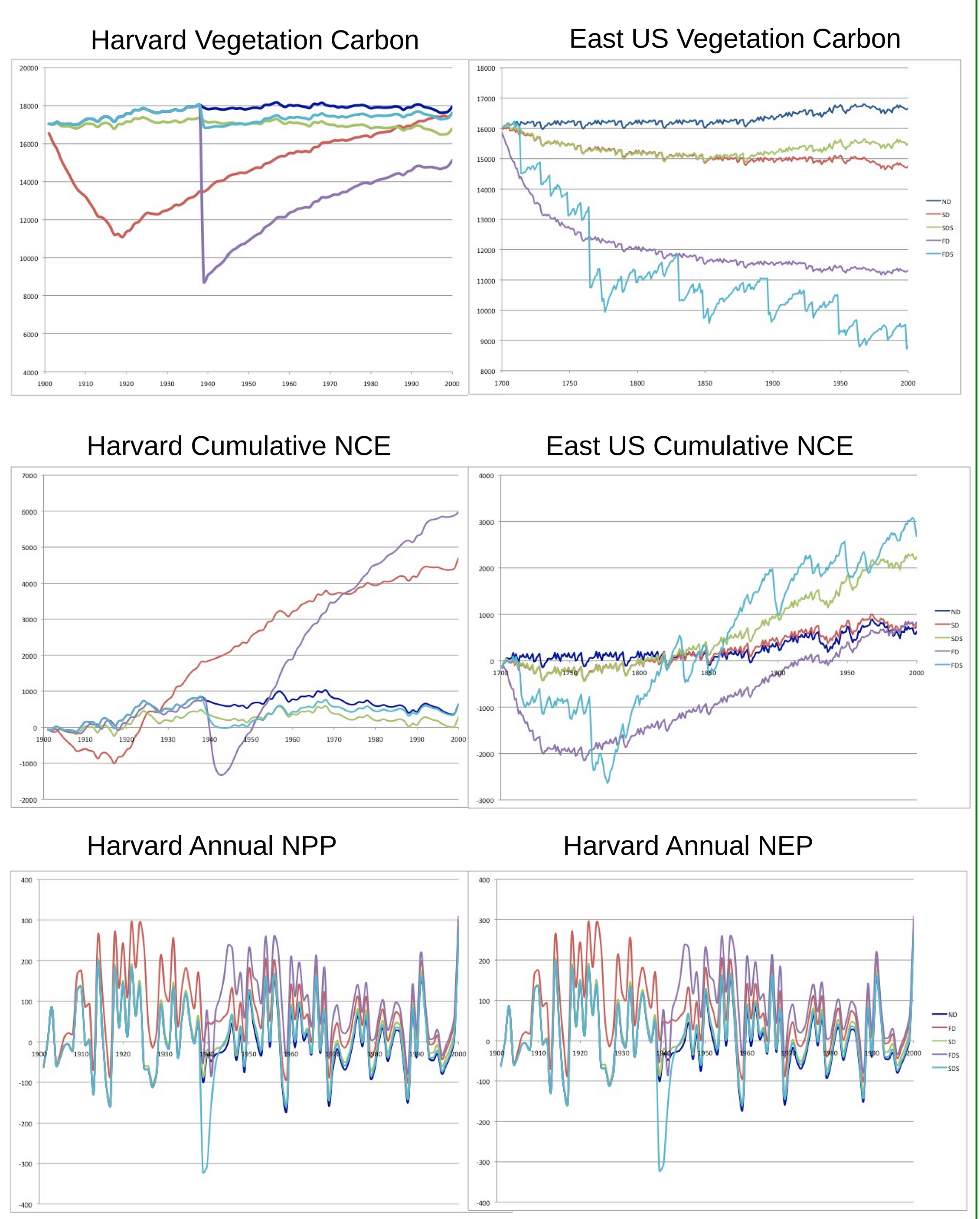


Figure 3.

TEM-Hydro: A process-based ecosystem model that uses spatially referenced information on climate, elevation, soils, vegetation and water availability to estimate fluxes and pool sizes of vegetation and soil carbon and nitrogen (Fig. 3). Compared to previous versions of TEM, we now explicitly model specific components of vegetation carbon and nitrogen (fine roots, sapwood, heartwood, leaves, labile pool) in order to capture the role of stomatal conductance on transpiration, CO_2 and ozone uptake. The dependence of stomatal conductance on photosynthesis and CO_2 is calculated by the Ball-Berry method (Ball et al., 1987), and the calculation of transpiration and soil evaporation is via the Shuttleworth-Wallace (1985) approach.

Results



Conclusions

- The disturbance reduces vegetation carbon that is ultimately not balanced by regrowth.
- Fire had a significantly stronger effect than storms on the stocks (i.e.vegetation and soil carbon), and in most cases, a somewhat stronger effect on the fluxes (i.e. NEP and NPP).
- At Harvard Forest, fire (FD and FDS) caused a noticeable increase in yearly NEP and NPP from regrowth.
- Regrowth caused NEP to marginally increase with disturbance in all cases for both experiments.
- For the eastern US, the decrease in NPP and the increase in NEP imply a larger decrease in decomposition.
- Cumulative NCE values show large carbon sequestration by stochastic fire and smaller to no carbon sequestration in the other cases.

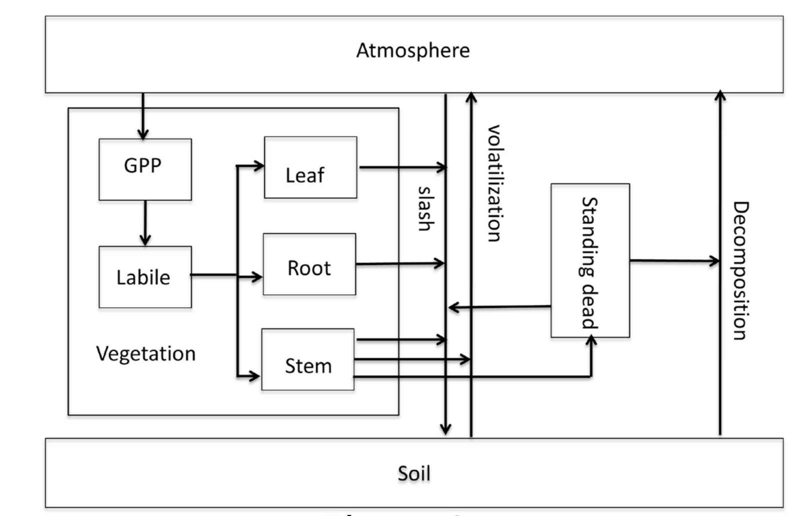


Figure 2.

East US 30 year average (from 2000):

	Vegetation C (gC/m²)	Soil C (gC/m²)	NEP (gC/m2/year)	NPP (gC/m2/year)	Cum. NCE (gC/m²)
FD - ND	-5360.00	-1118.67	51.78	-73.72	-0.89
FDS - ND	-7370.86	-1842.68	56.14	-165.88	1953.25
SD - ND	-1859.34	-345.27	9.41	-45.31	109.26
SDS - ND	-1156.97	-111.39	24.00	9.17	1456.49

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