An NSRC working group for improved modeling of Northern Forest Ecosystems

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- An improved PnET model was developed, made more accessible through creation of a user group and manual. Several improvements to model mechanisms include: improved response to higher atmospheric CO_2 concentrations and temperature, a multiple pool soil module, addition of nitrogen gas loss mechanisms, and coupling to a hydrological model.
- Simulations with the updated model indicate that future climate and land use in NH will likely increase above ground carbon stocks in northeastern forests and increase nitrogen export in streams.

Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service. http://www.nsrcforest.org

Project Summary

Rationale: Northeastern forests provide the region's inhabitants with a wide range of valuable services, including provisions such as fuel, fiber and clean water, along with nutrient cycling, carbon (C) storage and climate regulation. With expected changes in climate, atmospheric composition and land use, the degree to which these services can be maintained into the future is highly uncertain. Our ability to make reliable projections will depend on both improved assessments of ecosystem processes and on development of models that accurately simulate C, nitrogen (N) and water cycling under a range of environmental conditions and management scenarios. Development of an improved model of northeastern forests designed explicitly to simulate the effects of multiple environmental stressors on productivity, water quality and quantity, and C storage in northern forests is in great need.

Methods: Three phases of work were conducted: (1) a modeling workshop focused on identifying potential ways to increase model accessibility, improvements needed to mechanisms in the model, and potential applications and/or expansions of PnET; (2) incorporation of workshop results including creation of a user group and operating manual as well as and an improved core PnET model; and (3) application of the new model to predict changes in northern forest C, N and water cycles under future scenarios of climate, atmospheric composition and forest management.

Major findings: An improved PnET model and associated users manual was developed and released for use, which integrates updated responses to atmospheric CO_2 and temperature, a multi-pool soil module, gases nitrogen loss mechanisms and by coupling PnET with the hydrological model, FrAMES. Simulations with the improved model indicate that future climate and land use will likely increase above ground C stocks in northeastern forests and increase N export in streams.

Implications for the Northern Forest region: Climate will play an important role in determining the resources provided by northern forests. Forest management will need to consider the effects of a changing climate.

Background and Justification

- Forest ecosystems provide a number of vital services on which we all rely, including clean air, clean water, fuel, fiber and climate regulation. In the northeastern U.S., the degree to which forests will provide these services into the future is uncertain, due to changes that stem from stressors such as air pollution, atmospheric deposition, land-use intensification and climate change.

- Process-based ecosystem models, such as PnET that capture the dynamics of carbon, water and nutrient cycling in forest systems are particularly well-suited for assessing ecosystem health of northern forests under future change.

- Despite the large number of PnET users, model improvements resulting from various individual efforts have rarely been integrated across user groups.

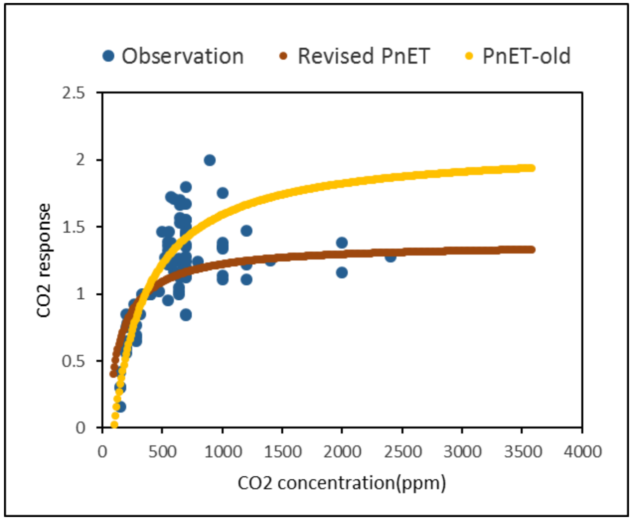
- This project brought together a group of scientists who broadly represent the PnET modeling community in order to integrate improvements accomplished by individual users, increase accessibility and centrality of the model, and apply an improved model to examine potential impacts of future climate scenarios on the services provided by Northern forests.

Methods

(1) We hosted a 2.5 day PnET modeling workshop (May 20-22, 2013) at the University of New Hampshire. The participant list (see "Collaborators" above) included 15 scientists from several Universities, private research companies, and government agencies. Each participant gave an oral presentation and participated in workshop discussions to outline steps needed to improve the existing model science, infrastructure, and accessibility.

Methods

(2) Priorities needed to improve model structure and functioning that were identified from the workshop discussions were then incorporated into an improved core PnET model. These included creation of an online user group forum, a user manual for new and existing users, and the improvement of several model mechanisms important in project forest response under future climate (e.g. an updated photosynthesis-CO_2 response curve and improved leaf respiration acclimation parameters).



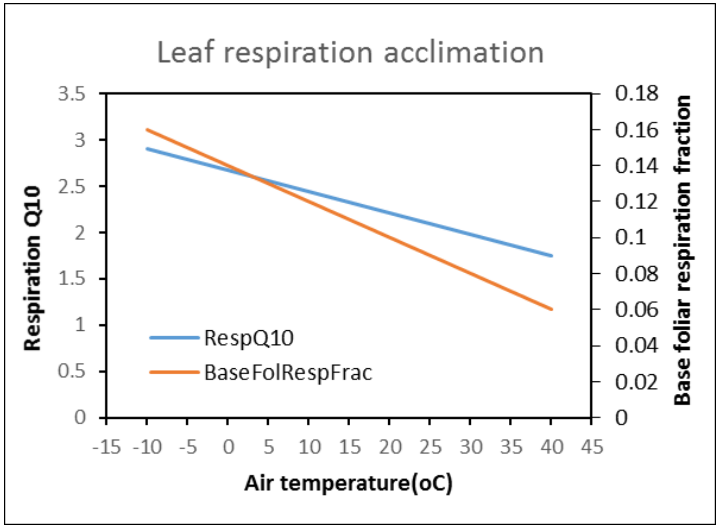


Figure 1: (Left Panel) Comparison of the original and updated CO_2 response curves to experimental data (Franks, et al., 2013). CO_2 response (y-axis) represents the relative change in CO_2 uptake through photosynthesis to changes in the concentration of atmospheric CO_2 (350ppm). The updated response curve (brown line) has a much lower response under high CO_2 than the original response curve which was created when data on the response to increasing CO_2 were lacking. (Right Panel) The leaf respiration acclimation curves. The original fixed Q10 (i.e., 2.0) for leaf dark respiration was updated by a linear relationship between Q10 and mean air temperature (left y-axis). The base foliar respiration relative to photosynthesis in photosynthesis was updated from 0.1 to a negative dependence on air temperature (right y-axis).

Methods

(3) Application of the new model linked with a hydrological model (FrAMES) to predict changes in northern forest C, N and water cycles under future scenarios of climate, atmospheric composition and forest management.

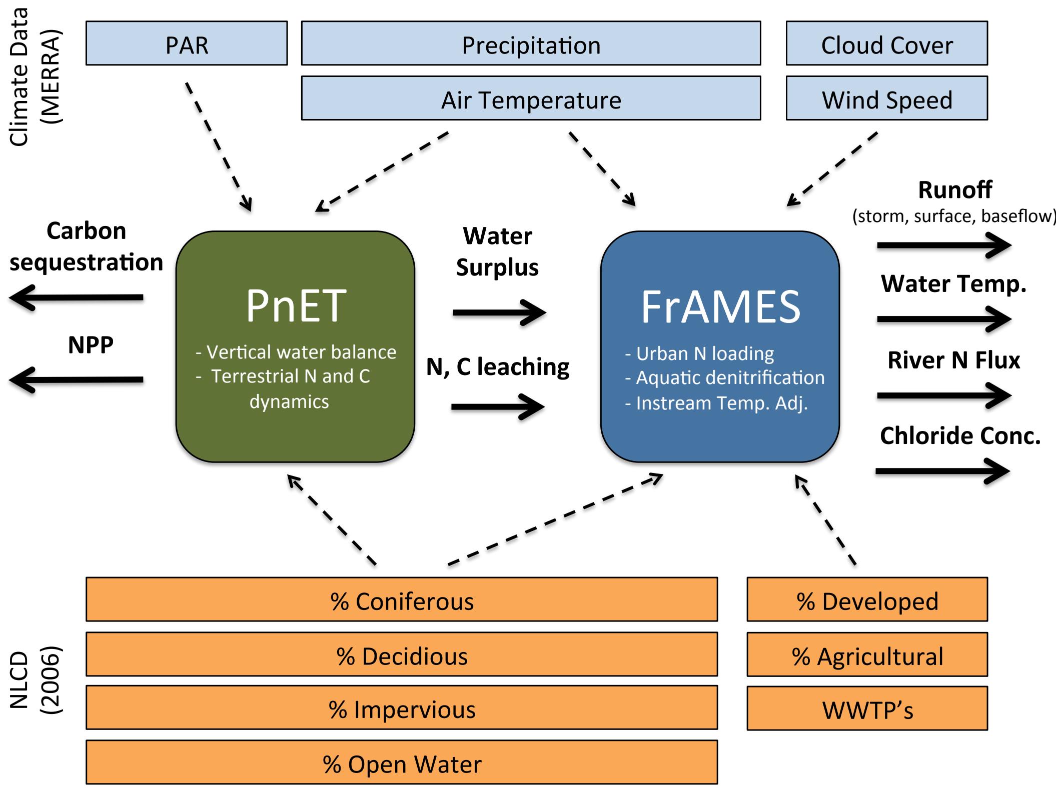


Figure 2: Conceptual diagram of the linkages between PnET and the hydrological model FrAMES under scenarios of climate, atmospheric composition and management. The climate projections included downscaled GFDL(2001-2100) high (A1FI) and low (B1) emissions. Land use change projects included five contrasting scenarios.

Results/Project outcomes

Model development:

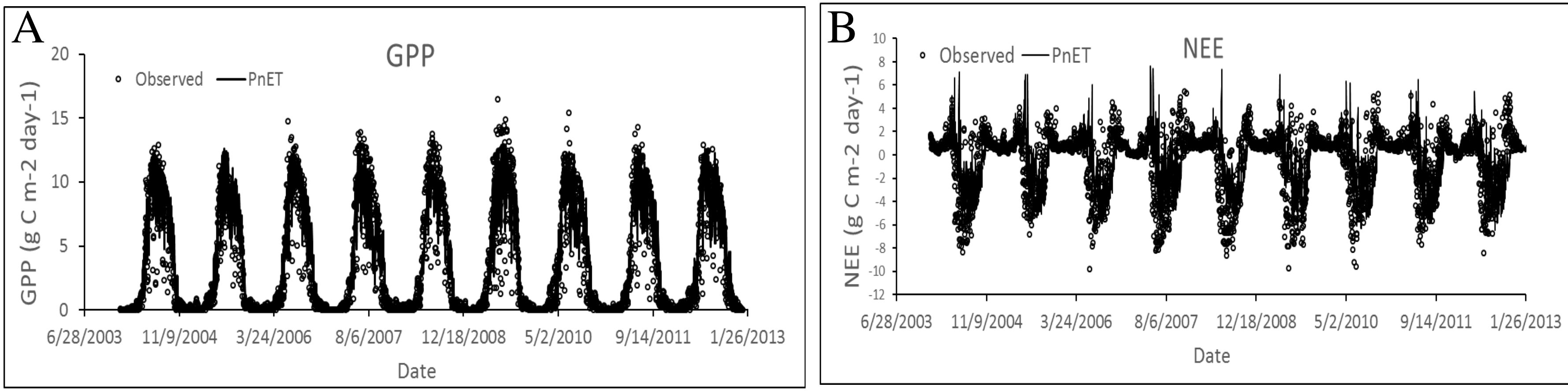
The specific mechanisms that improved the core PnET model include: an improved photosynthesis routine through an updated CO_2 response curve and temperature acclimation of foliar respiration, addition of denitrification, an improved representation of through inclusion of multiple soil pools each with a distinct turnover time to replace the single pool model originally in place, and coupling with the hydrological model FrAMES.

Model Accessibility

A PnET user manual was created with details on how to download (website), install, and run the PnET suite of models. The manual also contains a listing of default parameters used by past users across a variety of ecosystems. An online user group was created and was able to assist several researchers and PnET users. Large parts of PnET and ideas from PnET have also been incorporated into several other models including SPEC-N and LANDIS II.

Results/Project outcomes

Model validation:



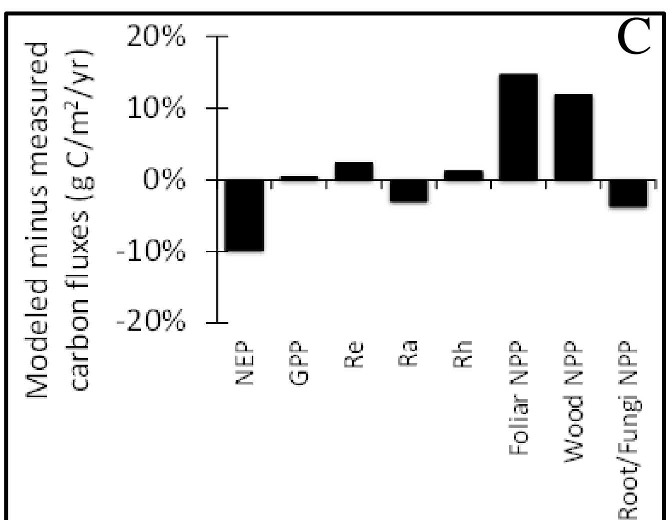
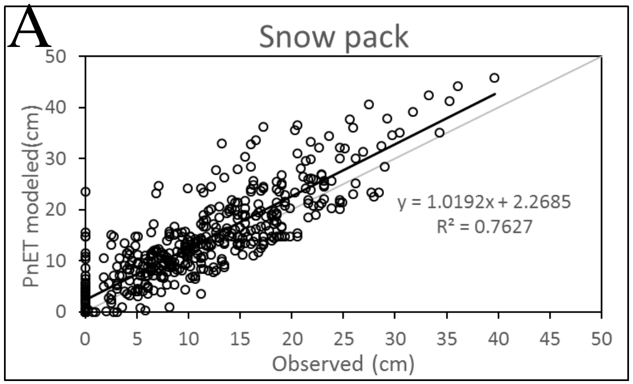
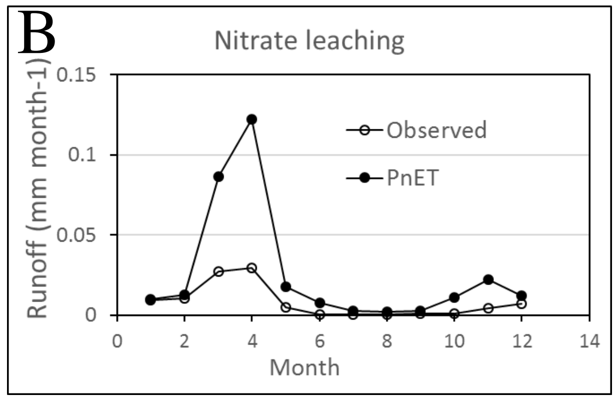


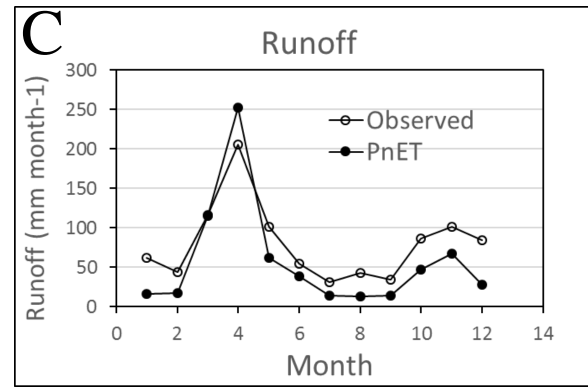
Figure 3: Dynamics of daily GPP (A), daily NEE (B) comparing estimates from the PnET model and the eddy covariance flux tower at Bartlett Experimental Forest, NH. C) Average PnET model bias compared to estimates from field data for ecosystem 13 year mean carbon fluxes at Bartlett Forest. Model estimates of carbon flux show good agreement with observations at multiple temporal scales.

Results/Project outcomes

Model validation:







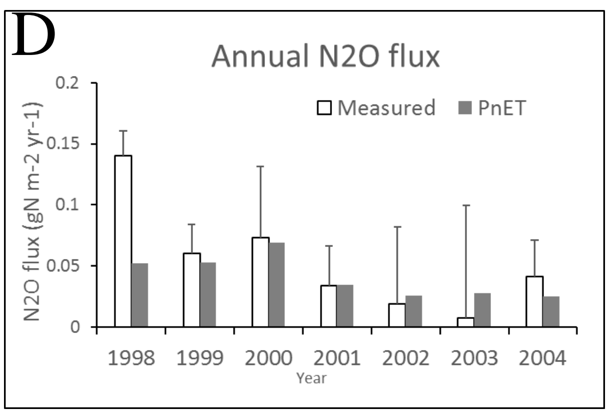


Figure 4: Comparison of modeled and observed snow pack (A), nitrate leaching (B), runoff (steamflow) (C), and N_2O emissions (D) at Hubbard Brook Forest. Modeled results are generally consistent with observations for water and nitrogen fluxes.

Results/Project outcomes

Model projection:

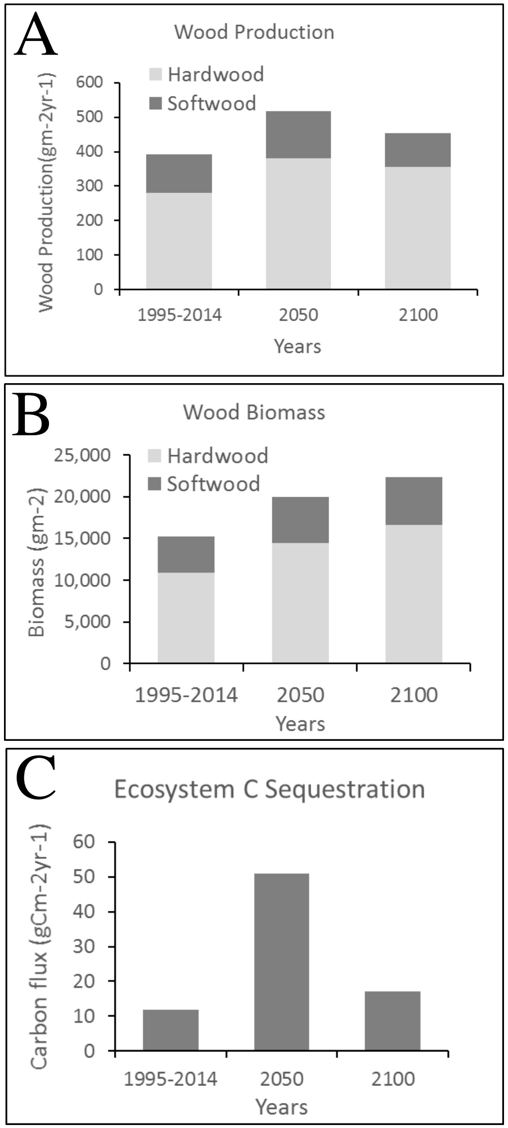


Figure 5: Preliminary modeling results of wood growth, woody biomass, and ecosystem carbon sequestration for the Merrimack River watershed. Model estimates are presented as averages for the entire watershed including forested and non-forested lands. For projections to 2050 and 2100 a range of climate and land use scenarios were used.

A) **Wood production** in the Merrimack river watershed:
• Model estimates of present day average hardwood and softwood production is about 280 and 113 grams/m^2/year, respectively. Under a range of climate and land-use scenarios projections from the PnET-CN model predicts that the average wood growth rates of hardwood species will increase by 33-39% and 22-32% compared to present day by 2050 and 2100 respectively. Softwood species are predicted to have more moderate (and in some cases decreasing) rates of wood growth through the end of the century.

B) **Wood biomass** in the Merrimack river watershed:
• Present day hardwood and softwood standing biomass average roughly about 10,922 and 4,346 grams/m^2, respectively. PnET-CN predicts increases in average hardwood standing biomass of 29-34 % and 47-56% bby 2050 and 2100 respectively, compared to present day stocks. PnET predicts an increases in average softwood standing biomass of 25-34% and 20-47% over that same time.

3. **Ecosystem C sequestration** in the Merrimack river watershed:
• Model estimates of the present day non-anthropogenic terrestrial net carbon sequestration rate of the whole watershed (including forested and non-forested areas) ranges from 7.8-16 g C/m^2/ year. Under a range of climate and land-use scenarios rates of terrestrial C sequestration are predicted to increase to 45-56 g C/m^2/year by 2050, and return closer to present day rates (7-27 g C/m^2/year) by 2100 at the end of 2000s.

Implications and applications in the Northern Forest region

- Climate change and land use change in NH in the future will likely increase above ground carbon stock in northeastern forests

- Due to nitrogen saturation and negative effect of increasing temperature on coniferous stands, nitrogen export will increase in streams with potential effects on water quality.

Future directions

- Conduct follow-up modeling using different forest management scenarios to explore impact of management on forest carbon, nitrogen, and water cycling in the context of climate change and land use change.

- Integrate forest composition dynamics in the modeling.

List of products

Publications:

1. Ouimette AP, Ollinger SV, Hollinger D, Richardson A, Keenan T, Vadeboncoeur M, Lepine L. (*in review*). Ecosystem Carbon Fluxes and Their Potential Interannual Drivers in a Temperate Forest Assessed Using Multiple Approaches. *Agricultural Forest and Meteorology Special Issue*.
2. Zhou Z, Ollinger SV, Glidden S, Wollheim W. (*in prep*). Regional effects of climate and land use on forest ecosystem processes at three watersheds in northeastern U.S.
3. Zhou Z, Ollinger SV, Lepine L. (*in prep*). Landscape variation of canopy nitrogen and carbon assimilation in a temperate mixed forest.

Presentations:

4. Ouimette AP, Ollinger SV, Hollinger D, Richardson A, Keenan T, Vadeboncoeur M, Lepine L. (2017) Comparison of carbon flux estimates using 13 years of eddy covariance data and plot-level biometric measurements from the Bartlett Experimental Forest, New Hampshire. Oral presentation at 2017 Northeastern Ecosystem Research Cooperative Annual Meeting. Saratoga Springs, NY. March 28-29.
5. Ouimette AP, Ollinger SV, Hollinger D, Richardson A, Keenan T, Vadeboncoeur M, Lepine L. (2016) Comparison of carbon flux estimates using 10 years of eddy covariance data and plot-level biometric measurements from the Bartlett Experimental Forest, New Hampshire. Poster presentation at Ameriflux Meeting. Golden, CO. Sept. 21-24.
6. Zhou Z, Ollinger SV, Martin M, Lepine L. 2015 Estimating wood growth across the Hubbard Brook valley: an analysis linking imaging spectroscopy and ecosystem model PnET. Poster presentation at LTER All Scientists Meeting. Estes Park, CO. Aug 30-Sept 2.

List of products

Model development:

1. Establishment of a web-based PnET user group (https://groups.google.com/forum/#!forum/pnet-user-group)
2. Consolidation of multiple PnET versions across several software platforms to a single version in C++ modeling language, and release of the improved PnET C++ daily version online (http://www.pnet.sr.unh.edu/download.html).
3. Creation of a PnET application database that will provide users with a wide range of previously run example model scenarios and input parameters to facilitate the use of PnET to a wider audience. The first version has been released online (http://www.pnet.sr.unh.edu/download.html).

Collaboration/Outreach outcomes:

1. Through user group helped researchers use PnET, e.g. Dr. Zev Reuter running PnET C version to study C, N and water in Northeast, and Dr. Brady Hardiman and Afshin Pourmokhtarian from Boston University running PnET-CN to estimate biogenic fluxes in urban ecosystems.
2. Japanese visiting scholar at UNH, Dr. Shin Ugawa, used PnET to explore N isotope signals in ecosystems and the function of mycorrhizal fungi in forest carbon cycling.
3. PnET presentation at undergraduate class of Prof. Wilfred Wollheim