Identifying Sources of Uncertainty and Observational Constraints to Improve the Simulation of Long Term Carbon Sequestration in Northern Wisconsin

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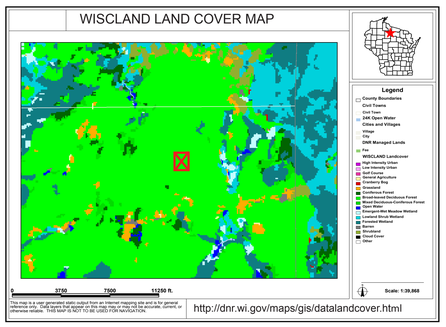
Background

A significant portion of uncertainty related to climate change is attributed to the terrestrial system feedback upon the climate. The Ecosystem Demography Model (ED2), a terrestrial biosphere model (TBM), is uniquely suited to help diagnose, quantify and predict the net exchange of carbon between the atmosphere and land, thereby specifying the sign and magnitude of the climate feedback. ED2 uses size and age structured vegetation equations to capture the competition that a single tree experiences for light and nutrients. This gap-level competition is important for simulating successional growth and long term carbon dynamics that other 'big-leaf' models may miss.

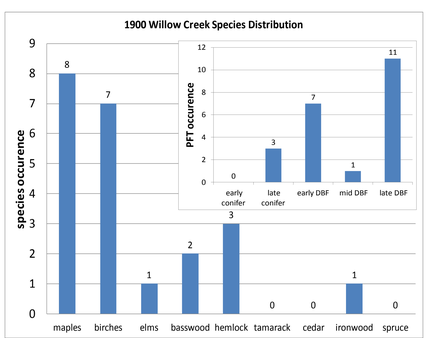
Our goal is to identify the most signifcant sources of parametric uncertainty within ED2 by performing a 100 year simulation at Willow Creek, Wisconsin (1901-2010). To that goal, we intend to perform a sensitivity analysis to identify the most signficant sources of uncertainty and then incorporate both existing and synthetic observations that best reduce the uncertainty.

Initial Vegetation Conditions

The Willow Creek site is located within the Chequamegon National Forest of northern Wisconsin. The present day tree stand (70-80 years old) within a 0.5 km radius of the flux tower consists primarily of sugar maple/basswood (75%) and green ash/red oak (20%). However, the surrounding area (see WISCLAND land cover map to right) is composed of aspen, elm and fir species. This region is ideal for study because it is part of an Ameriflux network of sites within the Chequamegon Ecosystem-Atmosphere Study, and has experienced both climate change and disturbance.



The vegetation conditions are estimated for the year 1900 from witness tree data that provides the species, tree diameter and aggregate stem density for two trees at each location. Eleven locations within 16 km^2 of the site coordinates were used to initialize the model. We assume that the site is composed of 11 patches populated by 2 cohorts each consisting of the type and stem density observed.



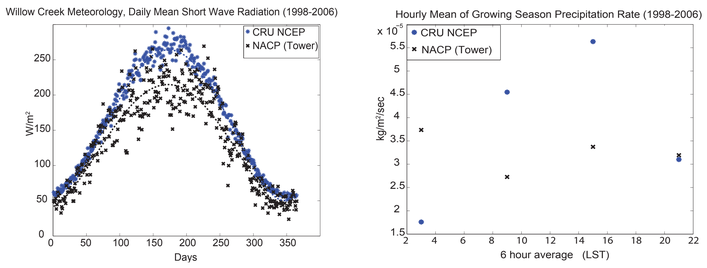
Meteorology

CRU-NCEP meteorology data (1901-2010) was used to drive atmospheric condtions within ED2. A 1 degree grid cell with 6 hour temporal resolution corresponding to the site coordinates, was adapted to drive the 13 variables: radiation (5), temp, precip, mixing ratio, pressure, wind (2), CO_2, and elevation.

1998-2006 Average Values							
Met Product	SW radiation W/m^2	LW radiation W/m^2	Precip kg/m^2/sec	Temp Kelvin	Mixing Ratio kg/kg	Pressure Pascal	Wind meter/sec
CRUNCEP	165	283	$2.48*10^{-5}$	278.13	0.0052	97900	3.02
Tower (NACP)	138	295	$2.26*10^{-5}$	278.48	0.0062	95200	3.15
% bias	19%	-4%	10%	-0.13%	-17%	2%	-4%

How well does the CRU-NCEP meteorology match the tower observed meteorology?

We examine the differences in magnitude by aggregating the 30 minute resolution tower meteorology to 6 hour resolution to compare the common years (1998-2006).



In general the CRU-NCEP meteorology is likely more conducive for vegetation growth given increased levels of shortwave radiation (+19%) and increased precipitation (+10%). The impact of these biases on carbon dynamics has not yet been quantified for this simulation.

Ecosystem Demography Model: Parameterization

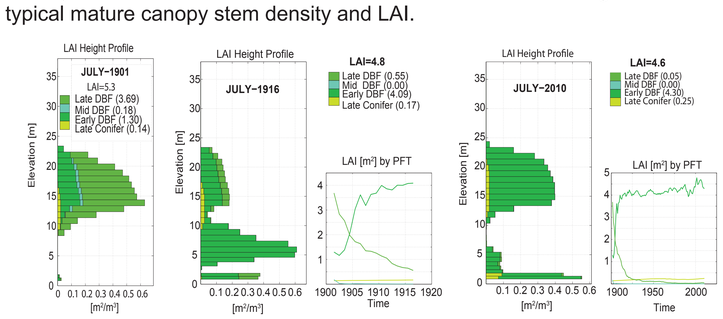
There are over 40 parameters per plant species that have the potential to influence carbon dynamics. The table below presents a subset of parameters that initial testing indicates is important for carbon sequestration, forest demography, and forest succession.

Willow Creek Select Parameter Settings (Default Values)										
PFTS	mort1	mort2	mort3	seedling mortality	r_fract	root turnover rate	growth respiration factor	storage turnover rate	quantum efficiency	dark respiration factor
units	year^{-1}		year^{-1}			year^{-1}		year^{-1}	mol CO_2/ mol photon	
Early DBF*	1.0	20	$6.14*10^{-3}$	0.95	0.30	5.77	0.00	0.62	0.08	0.02
Mid DBF	1.0	20	$3.81*10^{-3}$	0.95	0.30	5.08	0.00	0.62	0.08	0.02
Late DBF	1.0	20	$4.28*10^{-3}$	0.95	0.30	5.07	0.00	0.62	0.08	0.02
Late Conifer	1.0	20	$2.36*10^{-3}$	0.95	0.30	3.80	0.45	0.00	0.08	0.02
Description	density dependent mortality	density dependent mortality	density indpendent mortality	% of seed that dies	% of storage carbon to seed	fine root turnover	% daily carbon gain lost to growth respiration	carbon assimilate turnover	Farquhar (photosynthesis)	leaf respiration coefficient

*DBF = deciduous broadleaf forest

Willow Creek Default Simulation: (1901-2010)

The figures below are July snapshots of the leaf area index (LAI) profile of the simulated tree canopy. Parameters were taken from short term Willow Creek runs (<10 years) and were not optimized for the century time-scale. The stem density was increased from the witness tree observations to bring in line with typical mature canopy stem density and LAI.

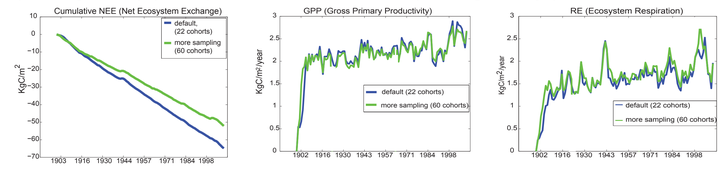


Despite a full overstory canopy (LAI=5.3, left figure) a surge in early DBF sapling growth occurs almost immediately (middle figure). The overstory mid and late DBF species die off within the first 40 years. The understory sapling growth matures and merges with the existing canopy by 2010 (right figure). Unrealistic understory stem density coupled with low carbon balance indicates mortality and/or seedling growth parameters require additional tuning.

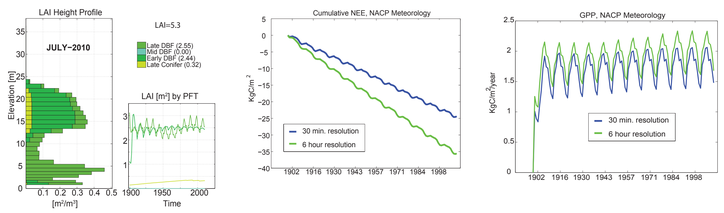
How sensitive is carbon sequestration to initial conditions and meteorology?

The figures below compare the default simulation (11 locations, 22 cohorts) with a run that was initialized from a wider sampling (in space) of the witness tree data (30 locations, 60 cohorts)

Although the photosynthesis and respiration processes are very similar (middle and right figure), the default simulation predicts 25% more carbon sink (~590 gC/m^2/yr) compared to the other run (~470 gC/m^2/yr).



The figures below compare simulations that use the observed tower meteorology (NACP) recycled throughout the simulation time period. The first simulation uses 30 minute resolution meteorology, whereas the second simulation averages the meteorology to 6 hour resolution. The coarser resolution meteorology increases carbon sequestration (+50%, middle figure) and unlike the default simulation, supports the growth of late DBF (left figure).



Additional Findings/Conclusions:

-ED2 requires additional parameter tuning to reduce unreasonable understory growth and die-off of initialized tree canopy. Based upon extremely high stem density and low carbon balance for specific cohorts, sapling and seedling mortality need to be increased.

-Performing a 700 year run with recycled NACP meteorology also simulates intense understory growth and reduction in late DBF LAI (1.0) from 1900-1950. However, late DBF begins to recover by 1950, then surpasses early DBF LAI shortly after 2100.

-Differences in model setup have not significantly changed carbon dynamics from the default run including 1) June vs January start date 2) choice of canopy sub-module 3) most recent model version ED2.2

-The CRU-NCEP meteorology is signficantly biased for some variables and the model is sensitive to meteorology resolution. This motivates the need to correct for meteorology biases.

Future Work:

-Once reasonable carbon dynamics are achieved the Predictive Ecosystem and Analyzer software (PECAN) (www.pecanproject.org) will be used to identify the most important parameters for determining 100 year carbon sequestration.

-A pre-calibration technique will be used to identify what current/ synthetic observations are most useful for reducing parametric uncertainty.

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