Modeling the Structure and Functions of Human-Dominated Ecosystems with a Hierarchical Patch Dynamics Approach

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Abstract

Global ecosystem has been intensively modified by human activities. To address the structural and functional complexity of human-dominated terrestrial ecosystem, a hierarchical patch dynamic model (HPDM) that couples the carbon/water/nitrogen processes is developed. Based on the hierarchy theory (Simon 1962; Wu 1999), ecosystem is modeled as interrelated subsystems that are in turn composed of their own subsystems, and so on, until the level of elementary is reached.

Using object-oriented programming technology, 7 hierarchical levels (Table 1), each of which is nested in the higher level, are modeled: plant organ, plant, population, ecosystem, land-use, landscape, and region. Spatial-temporal scales, dominant processes, drivers, and constrains for each level are identified and addressed in the model. HPDM aims to provide a tool for ecological extrapolation across multiple scales and also a flexible platform to study the responses of ecosystems to multiple anthropogenic stresses.

Model Information

Temporal Resolution**:** Daily

Spatial Resolution**:** Depend on inputs

Required Model Inputs

Parameters: physiological parameters for plant functional types; ecosystem composition & land-manage regime of each land-use type; crop rotation scheme.

Base maps: Elev, slope, Lat., Soil texture, pH, BD

Climate: Mean, MAX, and MIN temperature, precipitation, humidity and radiation (optional)

Atmosphere composition: CO2, N deposition

Land-management: annual N fertilization rate.

Model Outputs (116 variables) including:

Carbon fluxes: GPP, NPP, RA, RH, NEE, CH4

Carbon pools: VEGC, SOC, LTRC, DOC

Nitrogen fluxes: NMIN, NUPTAKE, N2O

Nitrogen pools: VEGN, SON, LTRN, SIN

Water fluxes: EVAP, ET, RUNOFF

Water pools: soil W(6 layers), intercepted W

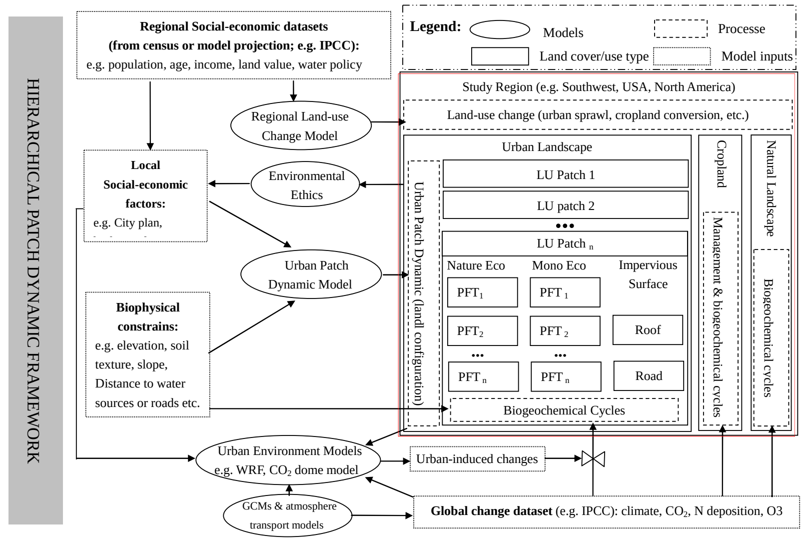

Figure 1, Illustration of the hierarchical patch dynamic framework. Red box delineate the HPDM.

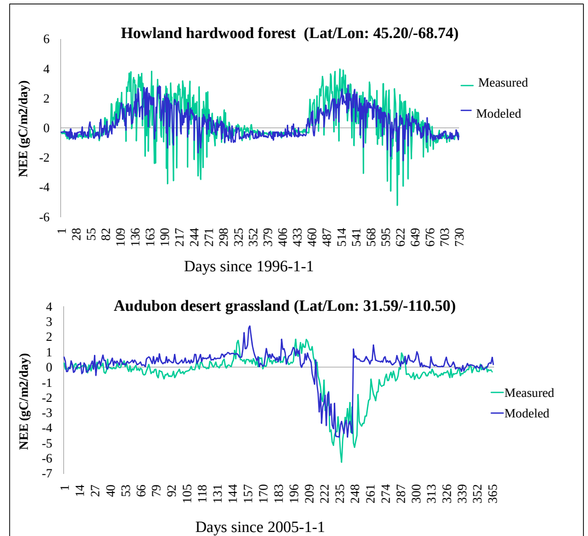

Figure 2, Model validation

Table 1, Modeling the hierarchical structure of terrestrial ecosystem

Hierarchical Level	Functional Types	Structure (components)	Spatial Scale	Processes	Temporal Scale	Major Submodels & Assumptions	Constrains and drivers	Outputs
Organ	Leaf, root, reproduct, storage, stem (sapwood, heartwood)	Organic Matter (Carbon (C), Nitrogen (N))	1 cm to 1 m	Evaporation and sublimation (EVAP_leaf), photosynthesis (PSN), transpiration (Trans), maintenance respiration(Rm), water & N uptake (WUP/NUP)	Second to hour	Energy balance (Penman-Monteith equation), PSN (Farquhar model)	Biomass, surface temperature & moisture, leaf water potential, incident radiation, ambient VPD & CO2	Daily PSN, EVAP_leaf, Rm, WUP & NUP
Plant	Tree, grass (C3 & C4), and shrub	Organs (Leaf, root, reproduct, storage, stem)	1 m to 10 m	Growth and allocation of biomass to organs, turnover of organs, leaf phenology	Day, month, year	Allocation (Pipe model), constant C:N ratio	Physiological parameters of each PFT, resource (light, N, water) availability	NPP, Rg, biomass of leaf, root, stem etc., heigh & DBH of tree, crown size
Population	Tree, grass (C3 & C4), and shrub populations	plants, density (plant/m2)	1 m to neighborhood	Establish, mortality	Day to year	Average Plant Individual approach (Sitch et al. 2003)	Bioclimatic constrains (Haxeltine & Prentice 1996), resource availability	C, N, W fluxes and biomass on the population level
Ecosystem	Natural ecosystem, monoculture, cropland, impervious surface	Population FTs, soil (SW, SIN, DON, SOM, litter, CWD), products	1 m to neighborhood	Resource competition & succession, canopy energy partition; Soil processes: decomposition, N mineralization, trace gas emission, evaporation, water runoff	Day to year	Average Plant Individual approach (Sitch et al. 2003)	Microclimate (precipitation, daily temperature, humidity), CO2, N deposition, latitute, slope, aspect, soil texture	C, N, W fluxes and biomass on the ecosystem level, FPC, dominant PFT
Land-use (LU)	Residential, transportation, commercial & industrial, cultivated, natural areas	Ecosystem FTs with fixed coverage	Neighborhood or larger	Managements on ecosystem (e.g. lawn irrigation, fertilization, clipping, tree pruning, cropland fertilization)	Year to decade	Stable structure (i.e. ecosystem composition) for a certain LUFT	Social-economic backgrounds and environmental policy determine the LU structure and management regimes *	Biogeochemical dynamics in response to LU managements
Landscape (LS)	Nature, Plantation, Agriculture land, Urban	LUFTs	1 km to 100 km	Changes in local climate and atmosphere (e.g. UHI, CO2 dome, elevated N deposition)	Decade	Empirical parameters; Regional Climate Model *	Land planning and Environmental policy determined the structure of landscapes *	Spatial patterns of biogeochemical dynamics in landscape level
Region	e.g. Arizona, Southwest, US, Global	LSFTs	County to global level	Land-use change: urbanization, cropland conversion etc.	Decade to century	Land conversion submodel similar to the MBL/TCM model by Houghton (1995)	Historical land-use census data or future land-use projected by land use models	Spatial patterns of biogeochemical dynamics in regional to global level

* Not realized in current version. Will be incorporated into HPDM in the future.

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