Supporting information for Hurtt *et al*. (2002) *Proc. Natl. Acad. Sci. USA* **99** (3), 1389–1394. (10.1073/pnas.012249999)

Appendix 1

The ED model (refs. 1 and 2; this study) is a new mechanistic terrestrial biosphere model that simulates carbon, water, and nitrogen dynamics on time scales from hours to centuries and on spatial scales from meters to continents. The model is formulated as a physiologically based plant simulator coupled to models of below-ground hydrology and decomposition.

There are two fundamental spatial scales in ED, one over which external climatic and soil conditions are specified (e.g., 1 × 1 degree), and the other the approximate size of an individual canopy tree (e.g., 15 × 15 m). Within grid cells, individuals of different functional types of plants compete for local light, water, and nitrogen. Hourly rates of carbon gain and evapotranspiration for each plant are calculated based on the Farquahar and Ball and Berry submodels. Plants then allocate fixed carbon to growth of leaves, stems and roots following empirically defined allometric equations, and die stochastically at rates influenced by both their rate of carbon uptake and their plant functional type. The death of individuals within the plant canopy and their leaf litterfall gives rise to fluxes of carbon and nitrogen into the soil whose fate is then tracked by using a simplified version of the Century decomposition model.

Because ED is formulated as a spatial stochastic point process, its large-scale behavior can be computed through direct, brute force simulation. Instead, however, we are able to calculate its ensemble mean behavior more directly by solving the following system of partial differential equations:

$$\frac{\partial}{\partial t} n(\underline{z},\underline{x},a,t) = -\frac{\partial}{\partial z_s}[g_s(\underline{z},\underline{x},\underline{r},t)n(\underline{z},\underline{x},a,t)] - \frac{\partial}{\partial z_a}[g_a(\underline{z},\underline{x},\underline{r},t)n(\underline{z},\underline{x},a,t)]$$

$$-\mu(\underline{z},\underline{x},\underline{r},t)n(\underline{z},\underline{x},a,t) - \frac{\partial}{\partial a} n(\underline{z},\underline{x},a,t)$$

$$\frac{\partial}{\partial t} p(a,t) = -\frac{\partial}{\partial a} p(a,t) - \lambda(a,t)p(a,t).$$

In the first equation, $n(\underline{z},\underline{x},a,t)$ is the density of plants of size $\underline{z}$, type $\underline{x}$, age a, at time t. $\underline{z}$ is a vector of both structural (s) and living (a) components. $\underline{x}$ is a vector of functional types. $\underline{r}$ is a resource vector and μ is the rate of mortality. The first two terms represent growth, the third term is mortality and the final term is aging. The second equation tracks the proportion of the grid cell $p(a)$ that is in each age a since a disturbance. In most forested areas the rate of disturbance (λ) is determined by the rate of treefall-gap formation, whereas in dryer areas the rate of disturbance is often dominated by the fire frequency. Boundary conditions track recruitment and the consequences of disturbance events. Age-structured versions of the decomposition and hydrology model then track associated soil carbon, nitrogen, and water fluxes within patches of different ages.

Changes to the "Biology" of ED for the U.S.

Several changes to the biology in ED were necessary for extending it to the U.S. The most significant changes were to the biodiversity represented and to the fire submodel. All changes where constrained to remain consistent with previous ED estimates for South America.

Biodiversity. We expanded the functional biodiversity represented in ED to include key functional types found in North America. Additions included the parameterization cold deciduous evergreen needleaf functional type. Cold deciduousness leaf-on and leaf-off was parameterized by using a monthly average temperature criterion of 10°, a value that gave reasonable growing season lengths along transect of sites in the U.S. from Maine to Georgia. The evergreen needleaf functional type was parameterized by using allometric information on Spruce from Maine (3) and Canada (4), and by prescribing appropriate specific leaf area and leaf life span characteristics.

Fire. We revised and reparameterized the fire submodel in ED to simultaneously give reasonable large-scale patterns of fires in the U.S. as well as South America. Like the fire model developed for South America, the new fire model is a simple function of both local climate and fuel loads. Whereas the sub-model developed for South America used a simple soil moisture threshold to trigger the climate risk for fires, the new sub-model has a continuous risk function that rises steeply with the length of dry periods (defined here as the length of time pet > ppt). Other fire models have found similar metrics to be an effective predictor of the climate induced fire risk (5). The new fire sub-model is

$$\Phi_i(t) = B_i(t)\left(\frac{\overline{D}}{30{,}000}\right)^{10} \quad i = \text{pasture, secondary, natural}$$

$$\Phi_i(t) = 0 \quad \text{otherwise.}$$

In keeping with ED's previous fire sub-model, all biomass (*B*) is considered fuel. *D* bar defined as the annual average drought index. *D* bar is computed from rolling monthly estimates of the number of days pet > ppt. This model was constrained through time to give estimates of the annual total area burned estimates that are approximately equal to the national statistics compiled by Houghton *et al.* (6). Fire suppression was implemented by multiplying each Φ each time step by the spatially constant factor needed to maintain approximate agreement with the national statistics on fire.

Including Land Use and Land-Use History in ED

ED model can be readily modified track additional heterogeneity within grid cells associated with different land-use states and the movements of parcels of land between them. For natural, secondary, and plantation lands partial differential equations are of the form

$$
\begin{aligned}
\frac{\partial}{\partial t} n_i(\underline{z},\underline{x},\tilde{a},t) &= -\frac{\partial}{\partial z_s}[g_s(\underline{z},\underline{x},\underline{r},t)n_i(\underline{z},\underline{x},\tilde{a},t)] - \frac{\partial}{\partial z_a}[g_a(\underline{z},\underline{x},\underline{r},t)n_i(\underline{z},\underline{x},\tilde{a},t)] \\
&\quad - \mu(\underline{z},\underline{x},\underline{r},t)n_i(\underline{z},\underline{x},\tilde{a},t) - \frac{\partial}{\partial \tilde{a}} n_i(\underline{z},\underline{x},\tilde{a},t) \\
\frac{\partial}{\partial t} p_i(\tilde{a},t) &= -\frac{\partial}{\partial \tilde{a}} p_i(\tilde{a},t) - \lambda_i(\tilde{a},t)p_i(\tilde{a},t) - \sum_j \lambda_{j,i}(\tilde{a},t)p_i(\tilde{a},t),
\end{aligned}
$$

where i refers to land-use type (i.e. natural, crop, pasture, secondary, plantation), and $\tilde{a}$ is time since disturbance. Here disturbance is defined broadly to include both natural disturbance events (λ_i), and important land use events ($\lambda_{i,j}$) such as land abandonment and harvests. For crop and pastures, we use simpler "size-structured" equations that fuse all age-related heterogeneity into a single average condition. These equations are approximations designed to retain essential aspects of the full demographic heterogeneity that can develop in ecosystems.

As with previous versions of ED, allometric equations are used to convert plant densities into equivalent biomass units, and corresponding age-structured equations track associated below-ground carbon, water and nitrogen pools. This system of equations involves boundary conditions that track specify such states as the initial condition, and processes such as reproduction, and the state of patches of land following disturbance. The remaining boundary conditions can be summarized with the following rules. There are no conversions back to natural lands from other land uses. Land-use conversions are assumed to involve the clearing of vegetation. Forest harvesting is stand-age specific on secondary and pasture lands, with faster rotation on plantation lands. Forest harvesting rates are specified in the land use history reconstruction. Other land use practices include crop harvesting, grazing, and pasture maintenance. A fraction of grazing and harvesting is assumed to be returned to local litter pools. Finally, land-use transition rates themselves ($\lambda_{i,j}$s) are specified by a land-use history reconstruction product we developed and that we describe in Appendix 2.

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