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

Appendix 5

Miami-LU is a highly simplified nonmechanistic descendant of ED. It is designed to illustrate, by virtue of its simplicity, the key factors responsible for the large-scale patterns captured by ED. As in ED, the model explicitly tracks land-use change and the disturbance and recovery of ecosystems. But unlike ED, the model does not predict net primary production (NPP) and vegetation dynamics mechanistically. Rather Miami-LU simply prescribes NPP by using the empirically based Miami model (1) and has highly simplified parameterizations of plant allocation and disturbance. Miami-LU also has simplified parameterizations of plant litter fluxes, organic matter decomposition, and fire.

For each grid cell, Miami-LU can be represented as a system of age-structured partial differential equations that track heterogeneity in carbon stocks and fluxes within the grid cell. This heterogeneity is partitioned into land-use categories (*i* = natural, crop, pasture, secondary, and plantation), and stand age (*A*), the time since the last land-use event to a particular stand.

$$\begin{aligned}
&\frac{\partial}{\partial t}B_i(A,t) = \alpha G(t) - \left(\mu + \Phi_i(t)\right)B_i(A,t) - \frac{\partial}{\partial A}B_i(A,t)\\
&\frac{\partial}{\partial t}S_i(A,t) = (1-\alpha)(1-f)G(t) + B_i(A,t)\left(\mu + (1-c)\Phi_i(t)\right) - kS_i(A,t) - \frac{\partial}{\partial A}S_i(A,t)\\
&\frac{\partial}{\partial t}p_i(A,t) = -\frac{\partial}{\partial A}p_i(A,t) - \sum_{j\neq i}\lambda_{j,i}(A,t)\,p_i(A,t)
\end{aligned}$$

In these equations, *B* is structural biomass (kg C m^{-2}), *S* is structural litter and soil carbon (kg C m^{-2}), *p* is the area of the grid cell (m^2). The model tracks only structural carbon and its decomposition under the assumption that structural carbon is the most important stock to track on decadal time scales. Faster metabolic carbon pools have relatively little carbon and equilibrate on faster time scales, and slower "passive" pools are assumed to be relatively inactive.

The model begins by estimating the woody fraction of NPP by using the Miami model. Miami NPP is first converted to carbon units using a factor of 0.5, and then to a total NPP (above + below ground) (*G*) by multiplying by a factor of 1.33; 0.5 is commonly used in the conversion from dry biomass to carbon, and 1.33 is based on the assumption that 25% of wood (and wood production) is below ground (2). The woody fraction of NPP (α) was set to 0.38 to match the aggregate output from ED. However, this value gives a typical value for woody growth in midlatitude deciduous forests of approximately 3.8 t biomass/ha per year, which is comparable to values estimated from U.S. Forest Inventory Analysis data of 2.44-4.93 for seven states spanning a north south gradient (J. Caspersen, unpublished work).

Loss of biomass occurs at a density-independent mortality rate μ plus losses from fire (Φ), and aging. μ was set to 0.018 also to simulate aggregate ED results. In ED the background mortality rate is lower and is 0.012, but ED also includes additional physiological sources of mortality. Empirically based estimates of mortality in unharvested stands in seven states are also lower (0.009–0.012), but the estimate is in the middle of estimates of all stands, including those that were selectively harvested (0.09–0.027) (J. Caspersen, unpublished work). Litter loads into the litter and soil pool from structural fraction of leaf litter, mortality, and the fraction of biomass not combusted (10%) in fires. Decomposition of structural material occurs from a 1-box model with linear kinetics. For Miami-LU, a constant of $k = 0.021$ gave a reasonable match to aggregated ED results. Other losses include aging. Finally, the area of the landscape at a particular age and land use is affected by aging and land-use transition rates ($\lambda_{i,j}$). f is the fraction of leaf and root litter that decays on a fast-time scale and was set to 0.75. c is the fraction of material consumed in fires and was set to 90% as in ED. Finally, as in ED, we make the added simplification of explicitly tracking age-related heterogeneity only on secondary and plantation lands, and track only the mean condition of natural, crop, and pasture lands. This transforms the above equations for crop, pasture, and natural vegetation into simpler ordinary differential equations for those classes.

On secondary and plantation lands, land-use conversion events are “age-resetting” and involve boundary conditions that describe the state of newly created patches after land-use events. Boundary conditions in Miami-LU include the results of transfers between land use states (for secondary and plantation lands). These are handled the same way in Maimi-LU as in ED. The model is first initialized with only potential vegetation (i.e., no land use). The remaining boundary conditions are summarized by the following rules. There are no conversions back to natural lands from other land uses. Land-use conversions involve the clearing of vegetation. Forest harvesting is stand-age specific on secondary and pasture lands, with faster rotation on plantation lands using the same drivers as ED. Fifty percent of total biomass is removed during a harvest and 50% is returned to litter pools for decomposition on site. Land-use transition rates ($\lambda_{i,j}$) are specified by the reconstruction LUCY, described separately. Note this system is not closed, as carbon is removed from cropland and forest harvesting and grazing on pastures, and in fires.

The fire model used in Miami-LU was developed to burn primarily on savannas and grasslands. It was parameterized by using published relationships between ecosystem boundaries and climate parameters. The fire model is

$$\Phi_i(t) = B_i(t)(400 + 40 * T - P) \quad P < 400 + 40T, \quad i = \text{pasture, secondary, natural}$$
$$\Phi_i(t) = 0 \ \text{ otherwise,}$$

where T is average temperature (°C) and P is average precipitation (mm/y). Fires depend on fuel loads and dryness, a common feature of most fire models. The model was then constrained to give an area burned in 1,700 of more than 800,000 $\text{km}^2\ \text{y}^{-1}$, and subsequently reduced in intensity to less than 30,000 $\text{km}^2\ \text{y}^{-1}$ in 1990 to match statistics indicating the relevant history of fire suppression (3).

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2. Moorcroft, P., Hurtt, G. C. & Pacala, S. W. (2001) *Ecol.l Monogr.* **71**, 557-586.

3. Houghton, R. A., Hackler, J. L. & Lawrence, K. T. (1999) *Science* **285,** 574–578.