"The merits and challenges of the ED-based approach to vegetation modeling"

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representing the ED2 development team: David Medvigy, Marcos Longo, Ryan Knox, Michael Dietze, Abby Swann et al...
The Merits
Non Linear Averaging: big-leaf ecosystem models average over vertical and horizontal heterogeneity in the resource environments of the individual plants that make-up the plant canopy.

- This is problematic because the functions governing the ecosystem’s above-ground dynamics (growth, mortality & recruitment) are non-linear functions of the plant’s environment (Jensen’s Inequality)

$$f(\overline{X}) \neq \overline{f(X)}$$
“Big-Leaf” models tend to have unrealistic long-term ecosystem dynamics

Unrealistic timescales of response:
e.g. Above-ground biomass dynamics of evergreen tree spp. in IBiS

Comparison against observations at San Carlos (tropical forest) 2°N,68°W

Homogeneous Ecosystems: In big-leaf models there is a single environmental niche within each climate grid cell. Gause competitive exclusion principle → homogeneous ecosystems.
Symptoms of non-linear averaging in big-leaf biosphere models

1. Incorrect timescales of ecosystem response: transitions between ecosystem states occur too rapidly.
2. Lack of diversity: homogenous ecosystems comprised of single plant functional types.
3. Difficult parameterize: few ecosystem measurements are made at scale of climate grid-cells.

Ecosystem Demography (ED2) Model

(Moorcroft et al. 2001, Medvigy et al. 2009)
ED Model simulator dynamics at San Carlos (tropical forest) 2°N, 68°W: trajectory of above-ground biomass

- Pioneer
- Mid-successional
- Late successional
- C4 grasses

AGB (kgCm⁻²)

PDE-based approximation

Stochastic simulation
ED2: a size- and age-structured terrestrial biosphere model

\[
\frac{\partial n^{(i)}(z,a,t)}{\partial t} = - \frac{\partial}{\partial z} \left[ g(z,a,t)n^{(i)}(z,a,t) \right] - \frac{\partial}{\partial a} n^{(i)}(z,a,t)
\]
ch. in density of plant type \(i\), growth, ageing

\[
\frac{\partial p(a,t)}{\partial t} = - \frac{\partial}{\partial a} p(a,t) - \lambda(a,t)p(a,t)
\]
ch. landscape age distribution, ageing, disturbance

- accurately captures the behavior of a corresponding individual-based model by tracking the dynamic horizontal & vertical sub-grid scale heterogeneity in canopy structure.
ED Model: Regional pattern of above-ground biomass (AGB) after a 200 year simulation (kgCm$^{-2}$)
Formal approach to scaling vegetation dynamics: summary

3 important benefits:

- realistic short-term and long-term vegetation dynamics.
- functionally diverse ecosystems
- improved ability to constrain the model with empirical measurements that results in improved predictive abilities.

Demonstrated improved predictability in time. But what about in space?
Howland Forest (45°N, -68° W)
(no changes in any of the model parameters)

- hardwood basal area increment (tC ha⁻¹ mo⁻¹)
- conifer basal area increment (tC ha⁻¹ mo⁻¹)

net carbon fluxes (NEP)
The Challenges
Formal approach to scaling vegetation dynamics: summary

3 important benefits:

- realistic long-term vegetation dynamics
- functionally diverse ecosystems
- improved ability to constrain the model with empirical measurements that results in improved predictive abilities.
The principal challenge associated with size and age-structured biosphere models such as ED2 is the computational challenges arising from the disaggregated nature of the ecosystem (plant canopy & soil column).
The additional challenge is that, due to the formal scaling that is embodied in the ED2 dynamical equations, the structure, composition, and resulting biophysical and biogeochemical functioning of the ecosystem are emergent properties.
# Time scales in ED-2.1

<table>
<thead>
<tr>
<th>Time scale</th>
<th>Processes</th>
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<tbody>
<tr>
<td><strong>Seconds – 15 minutes</strong></td>
<td>Canopy air space</td>
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<td>Snow/pounding layers</td>
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<td>Soil layers</td>
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<td>Leaf boundary layer</td>
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<td><strong>2 - 15 minutes</strong></td>
<td>Photosynthesis</td>
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<td>Radiation</td>
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<td></td>
<td>Meteorological forcing (interpolated if necessary)</td>
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<td><strong>Daily</strong></td>
<td>Growth of active tissues</td>
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<td>Leaf phenology</td>
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<td>Storage</td>
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<td>Plant “maintenance”</td>
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<td><strong>Monthly (cohort dynamics)</strong></td>
<td>Structural growth</td>
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<td>Reproduction (cohort creation)</td>
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<td>Mortality</td>
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<td>Fire</td>
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<td>Cohort fusion/fission/extinction</td>
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<td><strong>Yearly (patch dynamics)</strong></td>
<td>Anthropogenic disturbance (patch creation)</td>
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<td>Tree fall disturbance (patch creation)</td>
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<td>Patch fusion</td>
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ED2 – Energy budget for each horizontal tile
Ecosystem Demography

Benefits

• realistic long-term vegetation dynamics.
• functionally diverse ecosystems
• improved ability to constrain the model with empirical measurements that results in improved predictive abilities.

Challenges

• disaggregated canopy
• Some dynamics in the ecosystem are emergent properties – this can make it harder to parameterize the model**
  
  **It may be harder to tune but it’s closer to the truth!
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Lab: David Medvigy, Naomi Levine, Ke Zhang, Marcos Longo, Tom Powell, Alex Antonarakis. Shirley Dong

References:
Medvigy et al. (2009) *JGR Biogeosciences* 114: G01002

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