Geosci. Model Dev. Discuss.,
https://doi.org/10.5194/gmd-2019-45-AC1, 2019

Geoscientific Model Development Discussions
Open Access
EGU

Interactive comment on "The biophysics, ecology, and biogeochemistry of functionally diverse, vertically- and horizontally-heterogeneous ecosystems: the Ecosystem Demography Model, version 2.2 – Part 1: Model description" *by* Marcos Longo et al.

Marcos Longo et al.

mdplongo@gmail.com

Received and published: 2 May 2019

Dear Dr. Kim,

Thank you for your positive feedback and suggestions on how to improve the motivation of this manuscript.

First, we would like to clarify that the developments presented in our manuscript reflect

changes since ED-2.0, as the technical description of ED-2.0.12 and ED-2.1 were not published and they are part of a continuous model development effort. In addition, while ED-2.0 solved the energy and water cycles at sub-daily time scales, the paper by Medvigy et al. (2009) does not describe the implementation of these cycles in the ED framework. Our manuscript describes, for the first time, the fundamental equations that govern the energy, water, and CO_2 dynamics in ED-2 (Section 3), and how we obtain each flux that is accounted for in the fundamental equations (Section 4).

Below we summarize the main developments between ED-2.0, ED-2.0.12, ED-2.1, and ED-2.2, which should clarify the differences between the versions.

ED–2.0

This is the first version of the ED model that seeks to solve the energy and water cycles independently for each patch and cohort. Most of the model biophysics was adapted from the LEAF-2 land surface model that is part of the Regional Atmospheric Model System (RAMS; Walko et al., 2000). The photosynthesis solver mostly follows ED-1 description (Moorcroft et al., 2001).

ED–2.0.12

- The ED-2.0 code was partially written in C (legacy from ED-1), and partially written in Fortran (legacy from RAMS). This created many challenges to correctly transfer information between codes written in two languages. By the ED-2.0.12 version, we had rewritten most of the code in Fortran (except for a few file handling functions that remain in C).
- We also switched the standard output to HDF5 (as opposed to ASCII), which allowed us to efficiently store many output variables segregated by cohorts and

patches.

We used this version as reference in the manuscript because it was the last version of ED-2 that used temperature as prognostic variable for leaf and canopy air space. In addition, this version had a code structure that was similar to ED-2.1 and ED-2.2, which helped to perform the inter-version comparison of energy and water conservation.

ED–2.1

- Leaf internal energy and canopy air space enthalpy replaced temperature as the prognostic variables. This change simplifies the solution of the energy balance, as we solve changes in energy directly from the energy balance. It also reduces the errors in energy conservation under high fluxes of water (which rapidly modifies the heat capacity of the pools) and eliminates the singularity of surface water energy at $0°\mathrm{C}$, when internal energy changes due to freezing or melting water, but temperature may not change.
- We replaced the ED-2.0 heat capacity for vegetation (based on total vegetation LAI for each patch) with cohort-specific heat capacity, which is scaled with the cohort leaf and wood biomass. To be consistent with the thermodynamic definition of extensive property, heat capacity must be linearly related with the mass of each component of the system (e.g. Dufour and van Mieghem, 1975), and the ED-2.1 and later versions are consistent with this definition.
- We replaced the LEAF-2-based surface layer model (Louis 1979) with the parameterization by Beljaars and Holtslag (1991), as the latter parameterization improved numerical stability of eddy covariance fluxes under stable conditions.
- We included an option to prescribe the silt, clay, and sand fractions of soils and use the general equations by Cosby et al. (1984) and Monteith and Unsworth

(2008) to determine the hydraulic and thermal properties of soils. In ED-2.0, soils were assigned one of the 12 fixed soil texture classes originally defined in LEAF-2 (Walko et al., 2000). This option allows using site-specific soil texture characteristics in ED-2 simulations.
- We implemented a capability to save the entire ecosystem and thermodynamic state of the model in HDF5 files, which can be used to resume interrupted simulations and yield exactly the same results of uninterrupted simulations. This option is useful when carrying out simulations with long runtime that are interrupted before reaching the end (e.g. power outage or computer clusters with queueing systems that restrict the maximum runtime for individual jobs).

ED-2.2

- We identified an important inconsistency in the definition of enthalpy. To be a true thermodynamic state variable, the values of enthalpy given a thermodynamic state must be path-independent (e.g. Dufour and van Mieghem, 1975). We identified that assuming latent heat of vaporization to be constant prevented the definition of enthalpy to be path-independent. We re-defined latent heat to be a linear function of temperature and derived a new equation for enthalpy. The new definition of enthalpy is described in detail in supplement S4, where we also demonstrate that the new definition of enthalpy meets the thermodynamic definition of state variable.
- We identified and included missing components of the energy cycle.
  - The transfer of internal energy of transpired water from soils to leaves before applying the enthalpy loss through transpiration (Eq. 95 and 96). Ignoring this transfer of energy caused errors in soil temperature dynamics, often leading to unrealistic values in shallow layers.

- The energy exchange associated with phase change (evaporation, transpiration, dew/frost formation) was corrected. Because evaporated/transpired (condensed) water effectively leaves (enters) soils and leaves, we must also account for the transfer of internal energy at the evaporated (condensed) surface. Ignoring this term leads to unrealistic variations of temperature, especially in surfaces with low heat capacity such as cohorts with low LAI.
- We implemented detailed conservation verification during the model execution, which now reports any violation of energy, water, and carbon conservation, generates detailed output of the violation, and interrupts the simulation.

- The photosynthesis solver was rewritten to allow temperature-dependent functions to be expressed as functions of Q_{10}. We retained the original Arrhenius-based functions as legacy options, but the new option increases the options for assimilating data into the model. In addition, the current Q_{10}-based parameters fix the low temperature optimum in tropical plants previously noted by Rogers et al. (2017). Importantly, we rewrote the photosynthesis solver to ensure that it would always converge to a unique solution for net assimilation rate, stomatal conductance, and intercellular carbon dioxide concentration given the environmental conditions. We describe the algorithm in detail in the supplement (S14).

- We implemented a complete mechanistic representation of leaf boundary layer conductance (Supplement S12.2) based on Monteith and Unsworth (2008), which accounts for leaf and branch characteristics for each cohort, and accounts for both the type of convection (free or forced) and the type of flow (laminar or turbulent). The original formulation was partially based on Monteith and Unsworth (2008), but it always assumed laminar flow and imposed a scaling factor based on total patch LAI, which led to numeric instabilities in sparsely vegetated areas.

- We implemented ground-to-canopy conductance formulations (Sellers et al., 1986; Massman, 1997; Massman and Weil, 1999) that accounts for the cumu-

lative drag profile of vegetated areas obtained from the cohort structure, as well as the stability of the surface layer (Supplement 12.3).

- We replaced the version control to GitHub, which makes the new code developments readily available to the scientific community and encourages users to post issues, bug fixes and pull requests to the main code repository in open and collaborative forums.

- We implemented a shared-memory parallelization of many subroutines that solve the energy, water and carbon cycles at sub-daily scale. These subroutines comprise most of the processing time in ED-2. The parallelization approach was written to take any number of cores, and it distributes patches per core based on core availability, and accounts for patch age to improve processing balance amongst cores.

We must point out that the list above describes the key regarding the energy, water, and carbon balance, and developments to improve efficiency and reproducibility of results, but it is not complete. The full list would be lengthy for a manuscript, but is available through the GitHub logs.

We will incorporate a summarized list of main developments between ED-2.0 and ED-2.2 in the revised version of this manuscript.

Best regards,

Marcos Longo, on behalf of the co-authors.

References

Beljaars, A. C. M. and Holtslag, A. A. M.: Flux Parameterization over Land Surfaces for Atmospheric Models, J. Appl. Meteor., 30, 327–341, 1991.

Cosby, B. J., Hornberger, G. M., Clapp, R. B., and Ginn, T. R.: A Statistical Exploration of the Relationships of Soil Moisture Characteristics to the Physical Properties of Soils, Water Resour. Res., 20, 682–690, 1984.

Dufour, L. and van Mieghem, J.: Thermodynamique de l'Atmosphère, Institut Royal Météorologique de Belgique, Gembloux, Belgium, 2 edn., 1975.

Massman, W. J.: An analytical one-dimensional model of momentum transfer by vegetation of arbitrary structure, Boundary-Layer Meteorol., 83, 407–421, 1997.

Massman, W. J. and Weil, J. C.: An Analytical one-Dimensional Second-Order Closure Model of Turbulence Statistics and the Lagrangian Time Scale Within and Above Plant Canopies of Arbitrary Structure, Boundary-Layer Meteorol., 91, 81–107, 1999.

Medvigy, D. M., Wofsy, S. C., Munger, J. W., Hollinger, D. Y., and Moorcroft, P. R.: Mechanistic scaling of ecosystem function and dynamics in space and time: Ecosystem Demography model version 2, J. Geophys. Res.-Biogeosci., 114, G01 002, 2009.

Monteith, J. L. and Unsworth, M. H.: Principles of Environmental Physics, Academic Press, London, 3rd edition edn., 2008.

Moorcroft, P. R., Hurtt, G. C., and Pacala, S. W.: A method for scaling vegetation dynamics: The Ecosystem Demography model (ED), Ecol. Monogr., 71, 557–586, 2001.

Rogers, A., Medlyn, B. E., Dukes, J. S., Bonan, G., von Caemmerer, S., Dietze, M. C., Kattge, J., Leakey, A. D. B., Mercado, L. M., Niinemets, U., Prentice, I. C., Serbin, S. P., Sitch, S., Way, D. A., and Zaehle, S.: A roadmap for improving the representation of photosynthesis in Earth system models, New Phytol., 213, 22–42, 2017.

Sellers, P. J., Mintz, Y., Sud, Y. C., and Dalcher, A.: A Simple Biosphere Model (SIB) for Use within General Circulation Models, J. Atmos. Sci., 43, 505–531, 1986.

Walko, R. L., Band, L. E., Baron, J., Kittel, T. G. F., Lammers, R., Lee, T. J., Ojima, D., Pielke, R. A., Taylor, C., Tague, C., Tremback, C. J., and Vidale, P. L.: Coupled Atmosphere–Biophysics–Hydrology Models for Environmental Modeling, J. Appl. Meteor., 39, 931–944, 2000.

Interactive comment on Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2019-45, 2019.