OFFICE OF BIOLOGICAL AND ENVIRONMENTAL RESEARCH
Earth and Environmental System Modeling

U.S. DEPARTMENT OF ENERGY | Office of Science

FATES: THE E3SM FUNCTIONALLY-ASSEMBLED TERRESTRIAL ECOSYSTEM SIMULATOR

The Functionally Assembled Terrestrial Ecosystem Simulator (FATES) is a next-generation numerical terrestrial ecosystem model that simulates and predicts growth, death, and regeneration of plants and subsequent tree size distributions (Fig. 1). It does this by allowing plants with different traits to compete for light, water, and nutrients, within an environment that tracks both natural and anthropogenic disturbance and recovery.

This openly available code, when coupled into an earth system model, allows representation of potential ecosystem responses to environmental resource availability (water, light, and nutrients), climate, and atmospheric compositional changes—and how ecosystem change alters earth system dynamics.

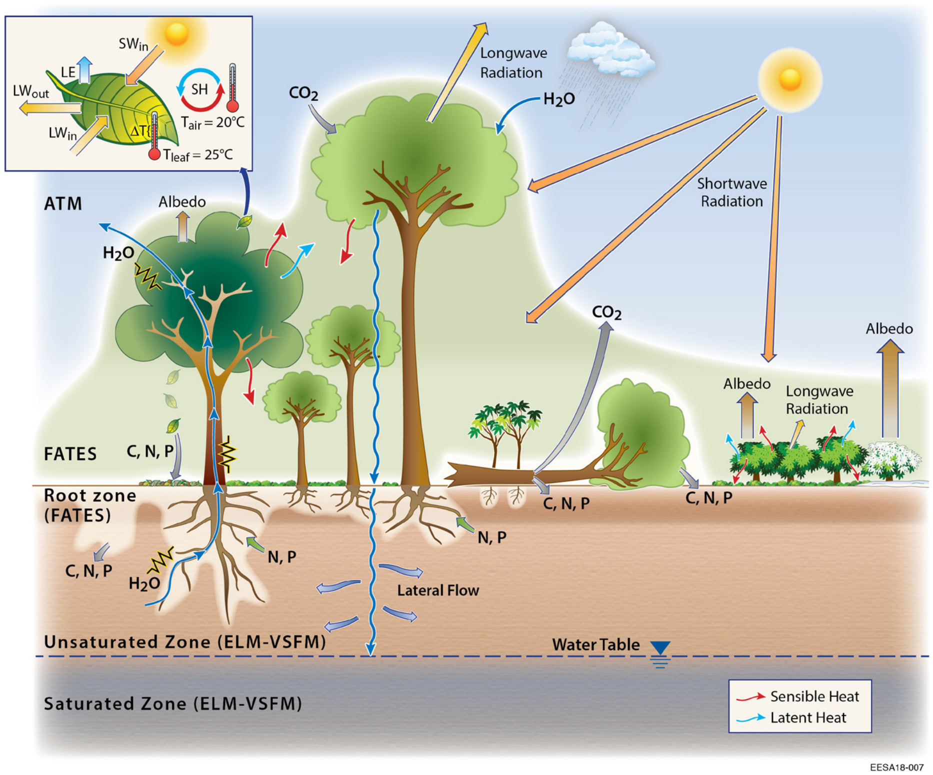

Figure 1. Conceptual overview of processes implemented in FATES, including multiple plant functional types of varying size-structure, multi-layered canopies, vegetation turnover, plant hydraulics, and plant nutrient competition between nitrogen (N) and phosphorus (P), as well as forest energy, water, and carbon cycling. Insert: Leaf-level energy and water fluxes. LE = latent heat, LW = longwave radiation, SW = shortwave radiation, SH = sensible heat. The FATES model is conceptualized in the green shaded area down to the root zone, with connections to processes linking to E3SM occurring outside this zone.

SIMULATING COMPETITION AT A FINE SCALE

FATES simulates competition for light and water, to predict plant coexistence and represents an ecosystem realistically (Fisher, et al., 2015).

Most earth system models (ESMs) use a coarse representation of plant communities as a single average of each plant functional type (Fig. 2). This precludes realistic representation of ecological dynamics. FATES provides a finer scale of plant diversity, separating vegetation into many ‘cohorts’ (similar height and functional types) across various ‘patches’ (area of similar time since a disturbance event). This allows the model to divide land surfaces into different successional stages (life-cycle phase).

For model successional stages and associated plant composition, FATES accounts for the differences between an abundance of ground-level light ranging from open canopy environments and arid regions to tropical rainforests. In these densely closed canopy ecosystems, arboreal competition in the canopy is fierce, and little light reaches the ground.

In tropical rainforests, successional stages are continual across the landscape. When a storm blows down trees, space is opened for light to reach the ground. First, fast-growing plants and grasses move into the open space. Decades later, slow but light-efficient trees move into the open space, eventually out-competing the ground-level plants.

Get FATES

Code and Software:
https://github.com/NGEET/fates-release

Documentation: **https://fates-docs.readthedocs.io/en/latest/index.html**

Changes in moisture conditions within plants, including stress-induced mortality during dry conditions, are predicted through individual- and trait-based plant hydrodynamic schemes that explicitly model water potential in soil, root, stem and leaf tissues.

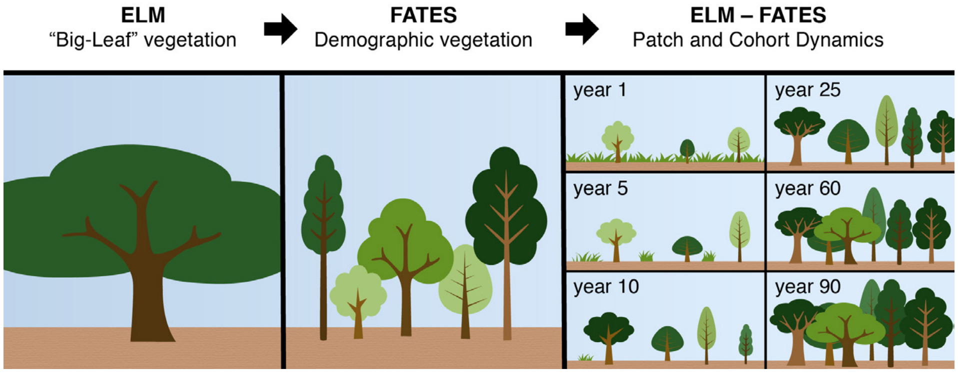

Figure 2. Coarse, homogenized representation of vegetation in ELM's 'big-leaf' version of the model, compared to demographic vegetation in ELM-FATES with heterogeneity in plant size, canopy, type as represented by 'cohorts,' and age since disturbance separated into different 'patches.'

EARTH SYSTEM MODEL INTEGRATION

Most current ESMs capture vegetation distribution based on static maps using bioclimatic envelopes and are not able to capture successional stages or shifts in biome boundaries. The capability of FATES to predict biome boundaries directly from plant physiological traits and competitive interactions is essential for modelers as they work to better understand ecosystem response to disturbances, and the future of climatically important fluxes of carbon, energy, and water.

Originating with the Ecosystem Demography model (ED), FATES introduces ecosystem demography (defined as distinct age- and size-classes of vegetation which can encounter multiple light environments) and dynamic vegetation into the structure of the land surface components of ESMs, allowing for full coupling to global atmosphere, ocean, and sea-ice processes. This integration allows ESMs to more precisely and realistically portray and study land ecosystem changes. FATES is currently coupled to DOE's **Energy Exascale Earth System Model** (E3SM) and the **Community Earth System Model** (CESM). Coupling FATES with these ESMs allows scientists to model current and future shifts in vegetation abundance, range, and survival.

High-fidelity representation of ecosystem function captures dynamics across ecosystems as diverse as tropical rainforests, temperate woodlands, boreal forests, and semi-arid grass and shrublands.

The FATES code offers a deep layer of granularity, with vegetation represented with similar biophysical properties, or traits—size structures, spatial scales, age, and response to disturbances, such as fire, drought, or deforestation. The net result is a more precise representation of real-world ecologies, such as accurate water, carbon, and energy cycles—a critical step in moving ESMs to realistic representations of a terrestrial ecosystem's impact on earth systems.

MODULARITY, FLEXIBILITY AND EXASCALE APPLICATION

The FATES code is designed to integrate easily into major ESM's and maintain the aspects of computational parallelism. It allows E3SM to simulate earth systems at higher resolution, without substantially reducing computation speed.

It is written with a modular and extensible design, with its communication with the land model consolidated to clearly demarcated code-spaces, such as boundary conditions. Object-oriented design concepts, such as class structures—with other features—make it possible to manage one FATES code base that can be connected efficiently with multiple different earth system land models.

The software is well-suited to future exascale deployment and would allow researchers to make predictions about tree size distributions, disturbance dynamics, and physiological processes of groups of trees. FATES can be tested and validated against field measurements and, therefore, serves as a comparative and predictive tool for modeling forested ecosystems.

SUPPORT

U.S. Department of Energy, Office of Science, Biological and Environmental Research (BER) terrestrial and modeling programs.

CONTACTS

Jennifer Holm, Ph.D., Ryan Knox, Ph.D., Charles Koven Ph.D.
Investigators
Lawrence Berkeley National Laboratory
jaholm@lbl.gov, rgknox@lbl.gov, cdkoven@lbl.gov

Dorothy Koch, Ph.D., Daniel Stover, Ph.D.
DOE Program Managers
dorothy.koch@science.doe.gov, daniel.stover@science.doe.gov

REFERENCE

Fisher, R. A., et al. (2015). **"Taking off the training wheels: the properties of a dynamic vegetation model without climate envelopes, CLM4.5(ED)."** *Geoscientific Model Development* 8, 3593-3619, DOI: 10.5194/gmd-8-3593-2015