LMWG Strategic Plan

The Community Land Model (CLM) is classically used as a tool to integrate terrestrial contributions and responses to weather, climate variability, and climate change. Today, land models such as CLM are increasingly expected to provide insight into climate and weather impacts on societally relevant quantities such as water availability, crop and timber yields, wildfire risk, human heat stress, and other ecosystem services (Bonan & Doney, 2018). CTSM/CLM development plans stem from needed model requirements to achieve these dual objectives as well as the need to enable the model to be applied to pressing research questions related to: (1) Ecosystem vulnerability to global change and feedbacks to global change from the terrestrial carbon cycle; (2) Identification of sources of weather, climate, and environmental predictability from land processes including those related to landscape heterogeneity; (3) Ecological prediction and forecasting; (4) Understanding the broad range of impacts of land use and land-use change on climate, carbon, water, and extremes, and (5) Water and food security in context of climate change, climate variability, and extreme weather.

Community Terrestrial Systems Model (CTSM) framework

Note that LMWG plans and development priorities will be developed in concert with development plans for the Community Terrestrial Systems Model (CTSM). CTSM is a unification of several land modeling efforts (principally CLM and the Noah-MP model used in WRF) and is being designed for broad applicability for research into climate, weather, water, and ecosystems. CLM no longer exists as its own entity and is now and will be a configuration of CTSM (CTSM-CLM). CTSM is being co-developed by CGD and RAL at NCAR in collaboration with national and international partners. Decisions about the configuration of future default versions of CTSM-CLM will be the responsibility of the CESM LMWG.

Development Plans

To develop a model capable of addressing the scientific goals outlined above, the LMWG has an ambitious model development program with an emphasis on eight key areas.

1. *Implementation and parameterization of the Functionally Assembled Terrestrial Ecosystem Simulator (FATES) ecosystem demography model.* The goal is to include FATES, which is developed in collaboration with DOE, as the primary vegetation model of CTSM-CLM for CESM3. FATES is a cohort model of vegetation competition and co-existence, allowing a representation of the biosphere which accounts for the division of the land surface into successional stages, and for competition for light between height structured cohorts of representative trees of various plant functional types. FATES is expected to provide substantially greater realism in terms of predictions of future ecosystem states and fluxes. By explicitly representing disturbance and other impacts, it is also expected to help address questions of ecosystem vulnerability. Simpler versions including the current vegetation and biogeochemistry (BGC) and prescribed vegetation (SP) schemes will be maintained for use in applications for which detailed ecosystem functioning is not required.
2. *Representative hillslopes and role of sub-grid heterogeneity on land-atmosphere interactions.* The inclusion of representative hillslopes will revolutionize the depiction of landscape heterogeneity through simulation of lateral water flow along elevation and water table gradients at scales (100s of meters) that are appropriate to the natural system. Impacts of slope, aspect, and co-variability of vegetation type with hillslope / riparian zone position are also represented. An initial implementation is in place and research efforts over the next several years will focus on definition of input datasets that define dominant hillslopes and their characteristics within each grid cell across the global domain. Note that FATES combined with representative hillslopes will be a powerful tool to examine interactions between water and ecosystem structure. Further, existing models do not account for the impact of strong heterogeneity in land fluxes on boundary layer/convection

processes. A Climate Process Team is developing methods for the transfer and use of heterogeneous flux information from the land to the atmosphere.

3. *Agriculture and water management.* Improved agriculture and water management allows for more detailed and informative examination of the impacts of climate change on food and water security. It provides the platform for research into land management as a climate mitigation tool and evaluates tradeoffs arising from different food, water, and energy management decisions. The LMWG development community is working on many projects to increase the realism of agricultural systems through improvements in crop phenology, representing processes such as tillage, shifting cultivation, spatially-explicit planting dates, biofuel crop parameterizations, manure and ammonia volatilization, and multiple irrigation methods. A new vector-based river model will be incorporated to permit explicit simulation of lake, reservoir and stream interactions, which then permits capability to simulate reservoir management and, in combination with groundwater withdrawal, a closed irrigation budget.
4. *Global parameter estimation*. Development of optimized global parameter estimation technique using emulators and machine learning. Significant efforts by the LMWG have gone into developing the infrastructure and expertise to conduct global parameter perturbation experiments and machine learning techniques to explore parameter sensitivity and optimization of the model. This work also required the implementation of a matrix solution for carbon and nitrogen which substantially accelerates model spinup and allows for unique diagnostics such as carbon residence time and attribution. We will develop an optimized land parameter set for CESM3 using these tools.
5. *Water isotopes*: This is a long-term need of the CESM project. By refactoring hydrology code in CLMto enable inclusion of a long-term maintainable water tracers (e.g., water isotopes) capability. to support
6. *MIMICS*. The development and evaluation of a microbial explicit soil biogoechemical model (MIMICS) is expected to improve the ecological realism of soil biogeochemical fluxes in CLM.
7. *Multi-layer canopy.* A new canopy flux model is being developed for CLM. The model updates the existing canopy flux parameterization for recent developments in leaf gas exchange, plant hydraulics, and canopy-induced turbulence. The equation set uses a fully implicit solution to calculate leaf temperature and fluxes, soil surface temperature and fluxes, canopy air temperature, and canopy air vapor pressure and is more numerically robust than CLM, which diagnoses, rather than prognoses, the canopy air space and can require many iterations to converge on a solution. An advantage of the multilayer implementation (in contrast with the single-layer used in CLM) is that the model distinguishes between the microclimate within the canopy and the coupling above the canopy with the boundary layer. This is particularly important in tall forests.
8. *Improved ease of use to broaden the applicability of CTSM.* The CTSM development team recognizes that a key requirement of success is model 'ease-of-use' through enhanced flexibility of model construction (e.g., runtime changes to number of PFTs and landunits, range of model complexity, multi-physics options) and spatial disaggregation (rectilinear, unstructured, and catchment grids). This includes the implementation of the Simple Land Interface Model (SLIM) into the CESM codebase. SLIM is an idealized, simplified and highly controllable land model with which users can explicitly control albedo, evaporative resistance, and surface roughness for studies of how specific regional land properties exert influence on the atmosphere. Also included within 'ease-of-use' needs are better tutorials, diagnostics, data analysis workflows (e.g., subgrid or FATES output), and simplified tool chains to generate input datasets and initial conditions.

Bonan, G.B., and S.C. Doney. "Climate, ecosystems, and planetary futures: The challenge to predict life in Earth system models." Science 359.6375 (2018): eaam8328.