Prognostic Land Use and Land Cover Change for CCSM: Coupling IMAGE and GCAM to CLM

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Objective

Improve knowledge of controls on future greenhouse gas concentrations and climate-biosphere feedbacks...

...by introducing predictions of human land use and land-cover change within a global climate-biogeochemistry model.
Project scope

- Transitions among managed and unmanaged vegetation types
- Crop, pasture, and forest management practices
- Including biofuel crops and carbon plantations
Prognostic biogeochemistry (CLM-CN)

Carbon cycle

Nitrogen cycle

Internal (fast)

External (slow)

Endogenous coupling

Exogenous coupling

Prognostic land allocation (IMAGE or GCAM)
Science Questions:

1. How sensitive are predicted land use change trajectories to inconsistencies in climate and BGC components of IAM & CCSM?

2. How sensitive are modeled climate-carbon cycle feedbacks to on-line vs. off-line representations of land use and land cover change?
Multi-phase coupling strategy

IAM (IMAGE or GCAM) → Fossil fuel emissions → CLM/CCSM

Fossil fuel emissions → LULCC → Climate

Climate → C stocks, productivity → Up/down scaling (space and time)

C stocks, productivity → Atm CO₂
Integrated Model to Assess the Global Environment (IMAGE v2.4)

- Dynamic land allocation algorithm
- Detailed treatment of managed land types
- Crops (7), pasture (2), carbon plantations, bioenergy crops
- External nitrogen cycle
- 0.5 degree grid
Coupling details: IMAGE + CLM

(a)

IMAGE v2.4
- C-cycle
- dynamic human land use
- C-plantations, bioenergy crops
- external N-cycle
- crop model

CLM-CN v4.0
- C-cycle
- internal N-cycle
- crop model
- dynamic natural veg (DGVM)
- prognostic fire

(b)

CLM-CN/IMAGE
- C-cycle
- dynamic human land use
- external/internal N-cycle
- crop model
- C-plantations, bioenergy crops
- dynamic natural veg (DGVM)
- prognostic fire

(from IMAGE v2.4) (merged) (from CLM-CN v4.0)
Coupling details GCAM + CLM

The iESM

Atmosphere

Land – iCLM

MiniCAM

ALM

Downscaling

Aggregation

Transition Matrix

NPP Yield

CLM++

Coupler

Sea Ice

Ocean

Details of Land Use/Land Cover Change Downscaling

Prognostic Land Use Classes from MiniCAM/ALM
- Forests
  - managed & unmanaged
- Food and Fiber
  - 9 types
- Bionergy
  - 2 types (grass & poplar)
- Pasture
- Non-Arable

Land Use Transitions (UNH Optimization Scheme)

- primary vegetation
- secondary forests
- crops (food, fiber, fuel)
- pasture

CLM Plant Functional Type Transition Matrix

Map - Global

% of plant
Model Development Tasks

1. Bring new plant functional types into CLM-CN (food crops, C-plantations, bioenergy crops).

2. Integrate internal N-cycle (CLM-CN) with external N-cycle (IMAGE).

3. Integration of historical datasets with expanded CLM-CN vegetation types from 1.

4. Integrate up/down scaling into CLM.
Next steps…

1. First phase coupling experiments:
   • Climate coupling with IMAGE (RCP 2.6)
   • C stock coupling with GCAM (RCP 4.5)

2. Second phase coupling experiments
   • C stock coupling with IMAGE
   • Climate coupling with GCAM

3. Tighten coupling
   • Integrate GLM/Peter Lawrence codes within CLM
   • Call IAMs as CLM subroutine

4. Introduce new CLM managed PFTs
CLM land cover transition logic

1. Coordinate CLM-CN land cover change data stream with “harmonization” approach for IPCC AR5.

2. Algorithms for handling both increases and decreases in area fractions, while conserving mass and energy.

3. New logic accepted as default approach for CCSM contributions to AR5.
CLM-CN Logic for dynamic PFT weights

Figure 1: Increasing weight

1. **Loop over PFTs**
2. **PFT weight increasing?**
   - Yes: **New PFT?**
     - Yes: **Initialize PFT (zero mass)**
     - No: **Add seed C and N for leaf and stem**
   - No: **to Figure 2...**
3. **Expand C and N to new area (conserve mass, reduce density)**
CLM-CN Logic for dynamic PFT weights

Figure 2: Decreasing weight

- PFT weight decreasing?
  - Yes: Leaf, live stem, and all storage and transfer pools to conversion flux.
  - No: to Figure 3...

- Fine root, live and dead coarse root pools to litter.

- Dead stem pool to conversion flux and wood products.

Loss to atmosphere (including fire):
- Wood product pools: 10-year, 100-year.
Task 3 summary…

CLM-CN Logic for dynamic PFT weights

Figure 3: Rotation harvest

Rotation harvest?

Yes

Retain area, remove mass, reduce density

Leaf, live stem, and all storage and transfer pools to conversion flux

Fine root, live and dead coarse root pools to litter

Dead stem pool to conversion flux and wood products

No

End PFT loop

PFT x

conversion

10-year

100-year

harvest

PFT x
(reduced density)

column