EaSM-3: Land Use Change and Land Atmosphere Feedback Processes as Regulators of Regional Climate Change

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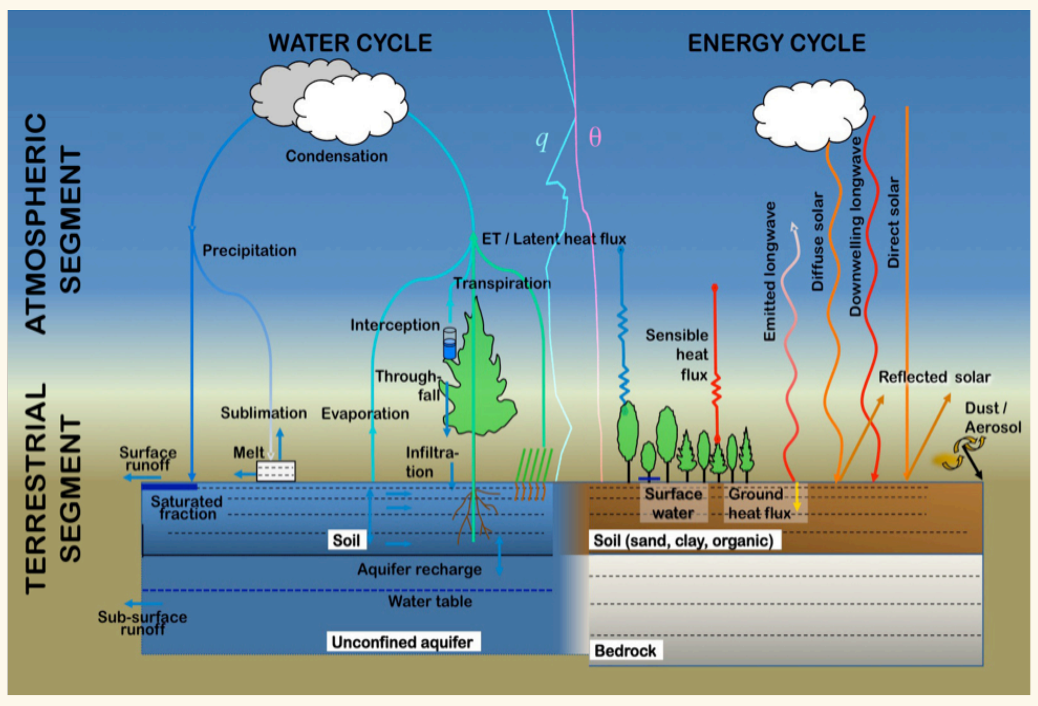
Introduction

How will regional changes in land use over the next several decades alter land-atmosphere interactions against the backdrop of a warming climate? The rate of climate change, frequency and severity of extremes, and predictability of climate variations are hypothesized to depend on the type of regional land use practices implemented in the coming decades.



The hydrologic and energetic components of the land-atmosphere system.

To determine the effects of land use changes – such as agricultural expansion, relocation, irrigation – on regional climate change, climate variability, and predictability, the coupled feedback processes between land and atmosphere in the Community Earth System Model (CESM) are being examined. This includes **analysis of important climate processes over land** with observational data and models.

Hypotheses

Two main hypotheses are proposed:

1. Regions of strong **land-atmosphere feedback** in the physical climate system (that affect quantities like temperature and precipitation) **will evolve** significantly in a changing climate.
2. Regionally, the rate of climate change, the frequency and severity of extremes, and the predictability of climate variability will be **dependent on the type of land use practices** implemented in the coming decades.

Goals

1. **Examine the coupled feedback processes** between land and atmosphere in CESM. This includes the relationships between soil moisture and surface fluxes, the connection between surface fluxes and the development of the atmospheric boundary layer, clouds and precipitation, and the role of the biogeophysical elements of CLM in these processes.
2. **Develop and refine metrics** for (a) quantifying land-atmosphere coupling in models and observations for purposes of model validation and the quantification of important climate processes over land; (b) land use changes in the context of their effects on, and response to, climate variations and change.
3. **Investigate the evolution** of coupled land-atmosphere climate processes in CESM **under the dual axes of a changing climate and regional land use change**.

Tasks

Task 1: Develop analysis tools for offline and coupled models

Confront CLM and CAM components of CESM with observations of land states (e.g., NASMDB, ISMN) surface fluxes (e.g., FLUXNET) and lower troposphere states (e.g. IGRA).

Task 1a: Land-atmosphere interaction diagnostics

- Metrics are being developed in cooperation with the GEWEX Global Land Atmosphere System Study (GLASS).

Task 1b: Metrics of modeled terrestrial response to land use

- Metrics are being developed in cooperation with LUMIP.

Task 2: Assess land-atmosphere coupling under varying land uses in CAM-CLM

Leverage progress made under a NASA-sponsored collaborative project to do similar evaluations NASA/GSFC and NOAA/NCEP models (without consideration of land use or climate change).

Task 2a: Land-atmosphere coupling assessment across CAM-CLM configurations

- Applications of metrics from Task 1.
- Informs development of CLM5.0 and CESM2.0 (to be used for CMIP6 and its related inter-comparison projects).

Task 2b: Analysis of offline CLM simulation across a variety of land covers and land uses

- These experiments will be conducted to examine the singular effects of the changes described in the specific experiments below in an uncoupled framework.

Task 2c: Analysis of land-atmosphere coupling across range of land cover / land use

- With the 'best' configuration from Task 2a, evaluate how land-atmosphere interactions differ in space and seasonally across a series of increasingly realistic treatments of agricultural land (see Task 3a).

Task 3: Decadal-timescale evolution of land-atmosphere feedbacks due to dual axes of climate and land use change

Ensemble simulations, assessments of means, variances, predictability and changes in metrics.

Task 3a: Assess changes in land-atmosphere feedback due to climate change and land use change separately

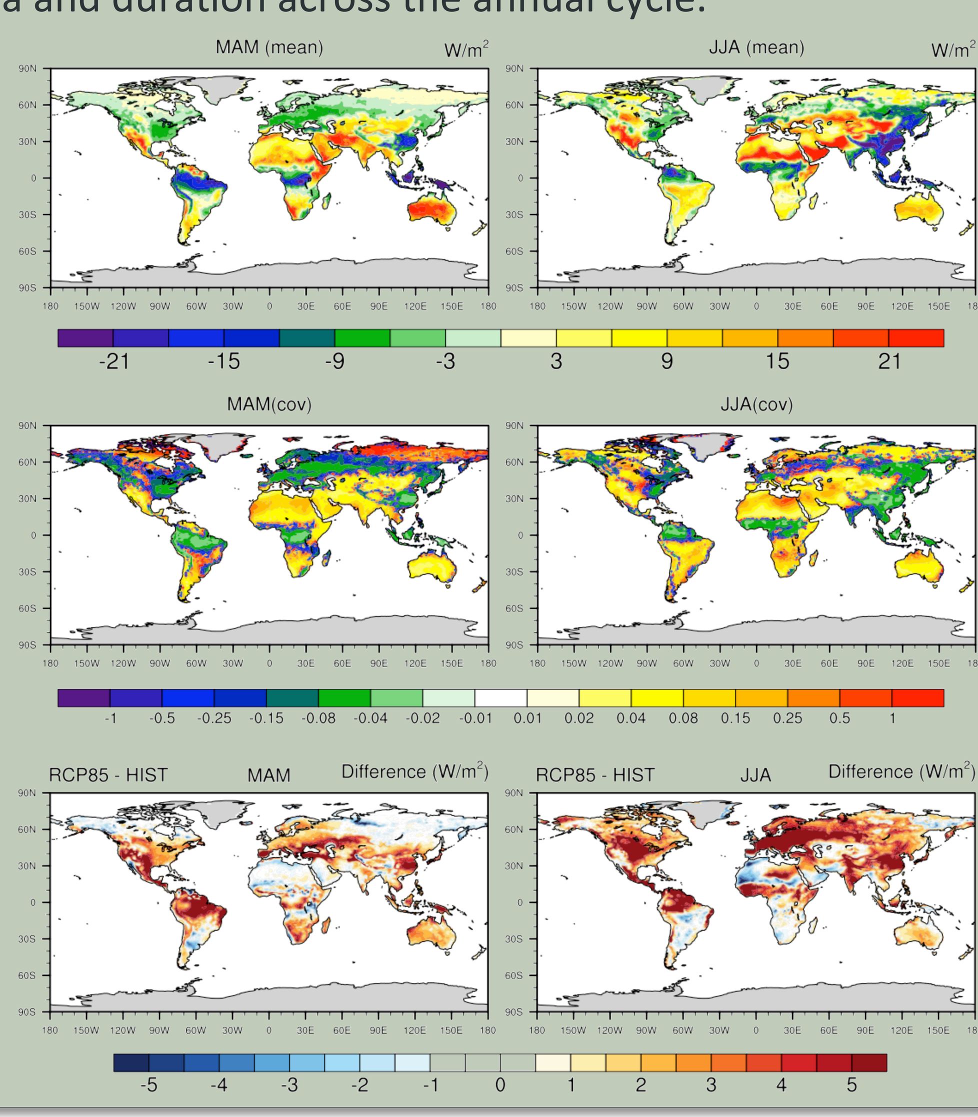
- Analyze impacts of: GHG and aerosols; land use changes; prognostic crop modeling; irrigation changes, land management practice changes.

Task 3b: Land-atmosphere feedbacks and impact on extremes under scenarios with both climate change and land use change

- Synthesis of most significant elements of Task 3a

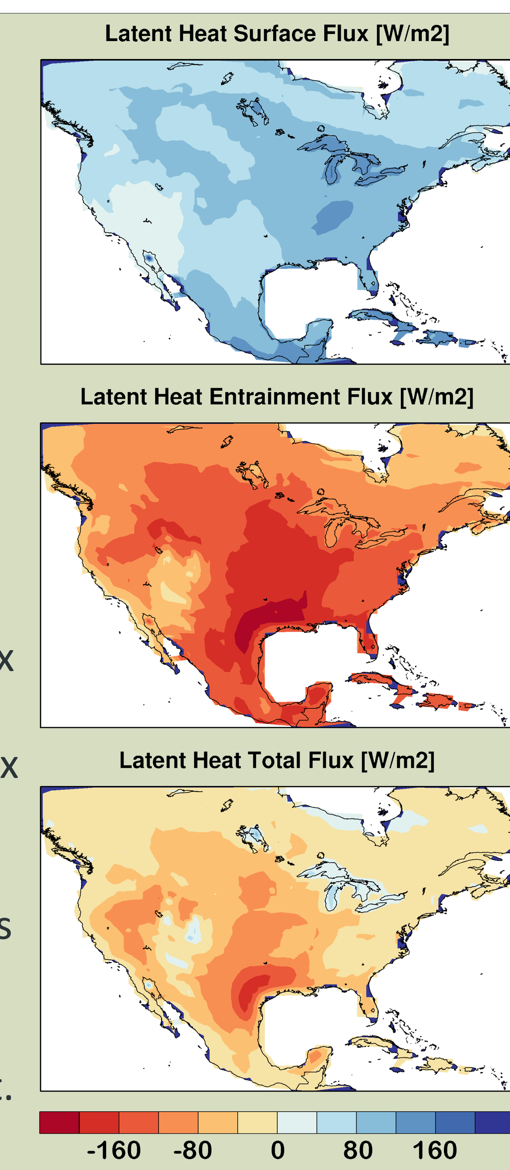
Stability of Coupling Metrics

Boreal spring and summer terrestrial coupling index between daily 10cm soil moisture and latent heat flux $r(SM,LH)\sigma_{LH}$ shows the classic "hot spot" regions (top row), and the coefficient of variation across LENS ensemble members (middle) indicates those hotspots are very robust. Climate change (bottom) will expand the hotspots in area and duration across the annual cycle.

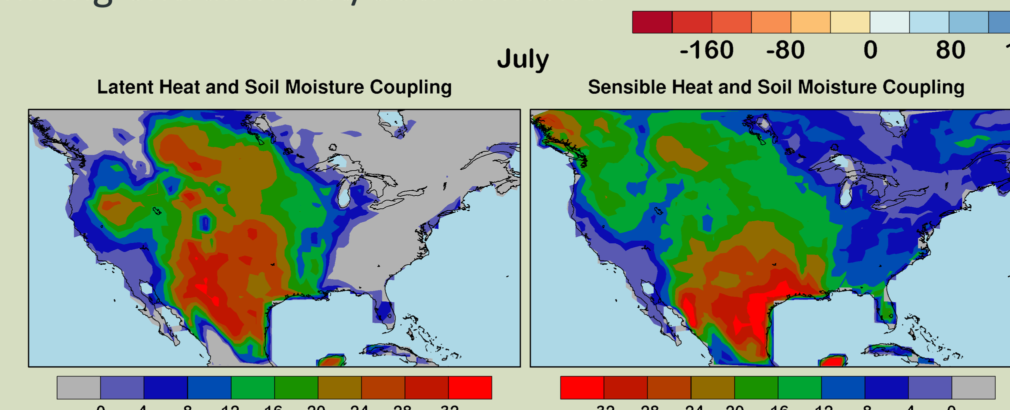


Boundary Layer Responses

Simulations with CAM5+CLM4.5 show large detrainment of water vapor from the top of the daytime boundary layer (right; center) that more than offsets the surface flux from evapotranspiration (right; top) during July over North America. Atmospheric moisture flux convergence largely makes up the difference (right; bottom).



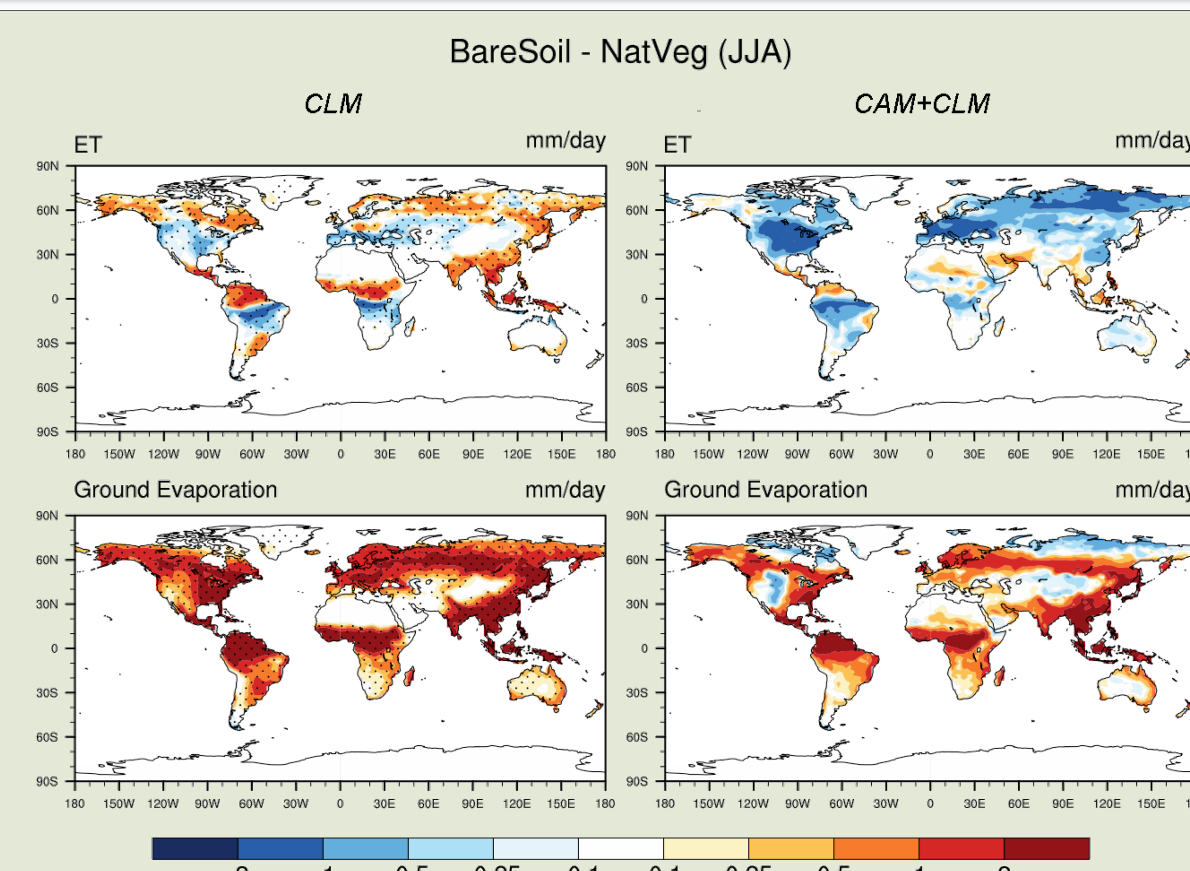
The pattern of this total latent heat flux out of the boundary layer strongly resembles the terrestrial coupling index between soil moisture and *sensible* heat flux, not latent heat flux (below). This is because sensible heat flux drives rate of growth of the boundary layer, which is the dominant factor determining entrainment/detrainment.



Sensitivity to Vegetation

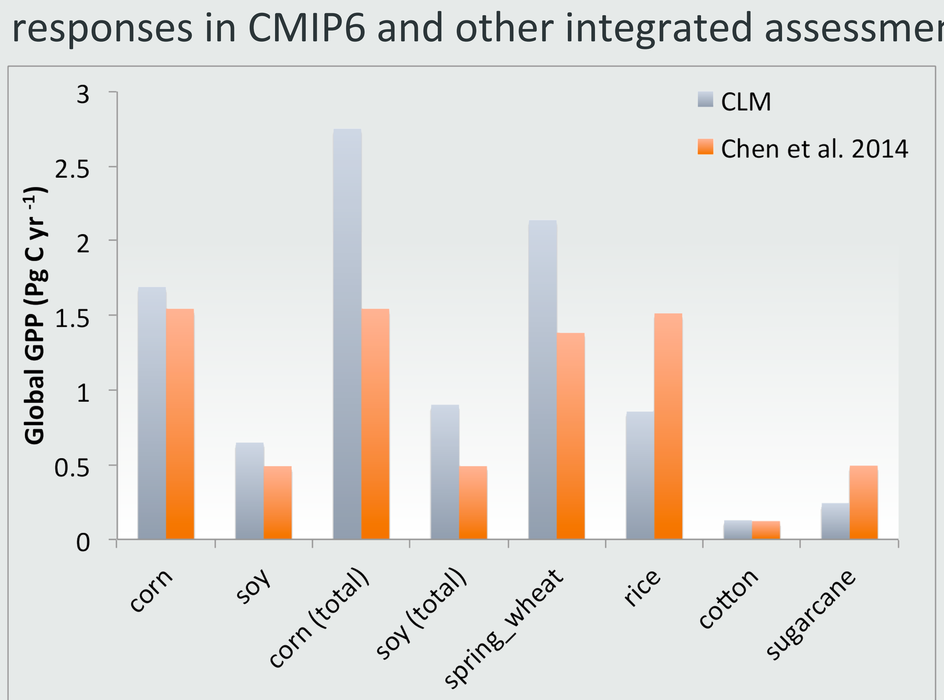
In multi-decade offline simulations (left column), replacement of all vegetation with bare soil results in a net increase of total evapotranspiration over many locations. This counterintuitive result is an artifact of the lack of feedbacks. In a coupled model, changes in surface heat fluxes result in changes to near surface temperature and humidity that reduce gradients and dampen the response – in uncoupled CLM simulations the atmospheric states cannot respond.

There is also a secondary effect brought about by changes in the atmospheric circulation and patterns of cloud and precipitation. The decreases in ground evaporation in the coupled simulations (bottom right) are largely due to areas or reduced precipitation, except in the arctic where cooler temperatures from higher albedos and prolonged snow cover hamper ground evaporation.



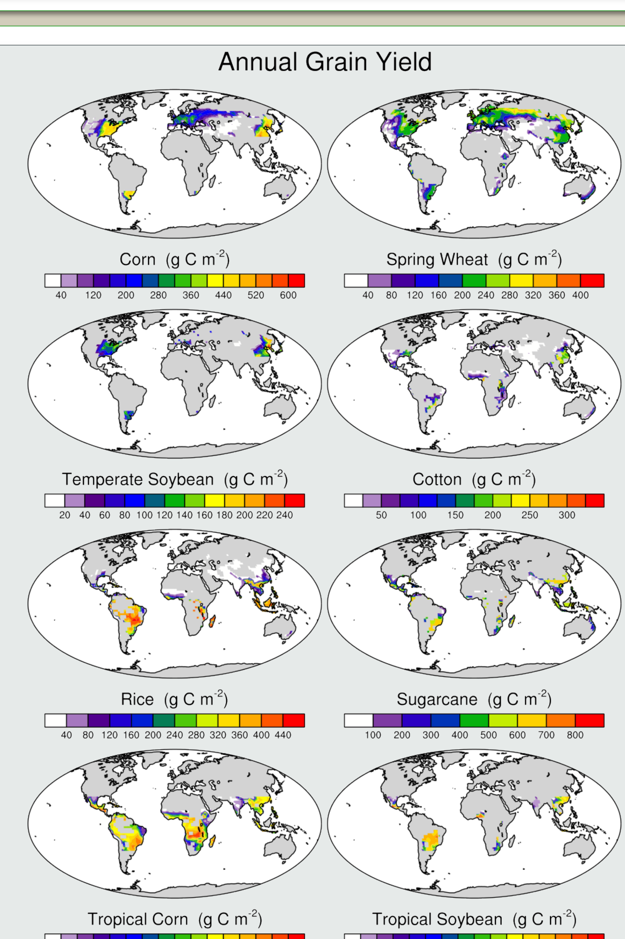
Crop Model Development

New diverse crop types including specific crops for tropical climates are being incorporated into CLM5. These will be crucial to improving land use change responses in CMIP6 and other integrated assessment simulations.



Left: Gross primary productivity for different crop types compared to global estimates.

Right: Global distributions of estimated crop yields under current climate from the new crop model under development for CLM5.



Project Management

The diagram below shows the anticipated sequence of tasks in this highly collaborative project.

Task	Description
1a	Develop L-A diagnostics
1b	Develop land use change metrics
2a	Assess L-A coupling in CESM configurations
2b	Assess CLM across land covers / uses
2c	Assess CESM across land covers / uses
3a	Assess coupling responses to land use or climate change
3b	Assess coupling responses to land use + climate change