SLIM: Simple Land Interface Model
(and some fun things you can do with it!)

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Why care about land-atmosphere interactions?

- Land covers ~30% of the Earth’s surface
- Most people live on land
- Humans manage most land that isn’t a desert, an ice sheet, or a pointy mountain (crops, grazing, forestry, cities, etc.)*

* Lambin & Meyfroidt (2011)
Climate matters for plants
Climate matters for plants and plants can influence climate.
Changes in land surface properties modify surface energy fluxes

- Shortwave Radiation
  - Albedo
- Longwave Radiation
  - Emissivity, $\text{H}_2\text{O}, \text{CO}_2$
- Sensible Heat
  - Roughness
- Latent Heat
  - Plant & soil properties
These changes in **surface fluxes** modify surface climate **directly**
These changes in **surface fluxes** modify surface climate **directly** and through **atmospheric feedbacks**

(e.g. through modifying rain, clouds, sun, air T, humidity, etc.)
In a typical modern Earth System Model (and the real world!), changing vegetation type means changing many things about the land surface at the same time.
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- In the real world, changing vegetation **does** change many properties of the land surface simultaneously

- But when a change in vegetation leads to an interesting atmospheric response, it can be hard to know what exactly the atmosphere is responding to...
In a typical modern Earth System Model (and the real world!), changing vegetation type means changing many things about the land surface at the same time:

- Vegetation height (roughness)
- Leaf area & color (albedo)
- Rooting depth (available water)
- Water use (available water)

Increased mid-latitude forests initially increase, then cause a big decrease in mid-latitude cloud cover. … but why? Trees are **darker**, have **deeper roots**, and are **taller** than grasslands… which of these drives the change in cloud cover?

Laguë & Swann (2016)
In a typical modern Earth System Model (and the real world!), changing vegetation type means changing many things about the land surface at the same time

- Don’t know which particular change in the land surface the atmosphere is responding to
- Can’t test properties individually (in a complex land model), because properties are either physically related to each other, or are **emergent properties**
In a typical modern Earth System Model (and the real world!), changing vegetation type means changing many things about the land surface at the same time.

- Vegetation height (roughness)
- Leaf area & color (albedo)
- Rooting depth (available water)
- Stomatal resistance, leaf area (evaporative resistance)
- Water use (available water)

Don’t know which particular change in the land surface the atmosphere is responding to.

Can’t test properties individually (in a complex land model), because properties are either physically related to each other, or are emergent properties.

To isolate the effects of a **single** land surface property on the atmosphere... use a **simple** land surface model instead!

Still coupled to a modern Earth System Model – test where the atmosphere is most responsive to specific changes in the land surface.
SLIM: Simple Land Interface Model

- Built a simple land model to couple to CESM in place of CLM
- Visited NCAR for several months through the ASP visiting graduate student program
SLIM: Simple Land Interface Model

- **Simple, very like early land models**
  Looks a lot like Manabe (1969); draws from LM2 (land portion of GFDL’s AM2LM2 model), LSM1 & BATS (pre-CLM land models)

- **Coupled to CESM**
  Here, using CAM5 & a slab ocean
  Used in place of CLM

- **Directly set each surface property**

- **Small... a few thousand lines vs. a few hundred thousand lines in CLM**
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- **Directly set each surface property**

  e.g. change **albedo** and know the rest of the climate system is **only** responding to that change in albedo
SLIM: Part of an Hierarchy of Models

Aqua planet

Idealized Land

Full Earth System Model

Basic land characteristics the atmosphere cares about, e.g. limited capacity to hold water
SLIM: Part of an Hierarchy of Models

Aqua planet  Idealized Land  Full Earth System Model

Useful anytime you don’t want full-complexity land

Directly control surface properties, avoid long land spin-ups, nutrient cycling, dying plants, etc...

But conserves energy and water and will play nicely with an atmosphere
With this tool (SLIM), we can do some fun things...

1. Global changes in land albedo and land evaporative resistance

2. Separating the climate effects of albedo, evaporation, and roughness from historical vegetation change
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- albedo
- evaporative resistance

Laguë et al. (2019)
Used SLIM coupled to CAM5 & a slab ocean to look at how global-scale changes in two specific land surface properties impact the climate system.

- Albedo
- Evaporative resistance

Directly modifies how much energy the land absorbs

Laguë et al. (2019)
Used SLIM coupled to CAM5 & a slab ocean to look at how global-scale changes in two specific land surface properties impact the climate system

- **albedo**
  - Directly modifies how much energy the land absorbs

- **evaporative resistance**
  - Repartitions energy between sensible and latent heat (no *direct* effect on total energy in the land system)
Used SLIM coupled to CAM5 & a slab ocean to look at how global-scale changes in two specific land surface properties impact the climate system.

Global changes to a **single** land surface property.

Laguë et al. (2019, Journal of Climate)
Effect of changing land surface properties on surface temperature

Albedo:

$\Delta T_s$ per 4% darkening of albedo

Laguë et al. (2019)
Effect of changing land surface properties on surface temperature

Albedo:

$\Delta T_s$ per 4% darkening of albedo

- Darker
- More energy in
- All else equal, should warm
- But how much it warms varies with location

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Effect of changing land surface properties on surface temperature

Albedo:

\[ \Delta T_s \text{ per 4\% darkening of albedo} \]

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*coupled SLIM-CAM5-slab ocean simulations

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Effect of changing land surface properties on surface temperature

Albedo:

$$\Delta T_s \text{ per 4\% darkening of albedo}$$

Big $\Delta T_s$ places where it is dry and sunny

*coupled SLIM-CAM5-slab ocean simulations

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Albedo:

$$\Delta T_s \text{ per 4% darkening of albedo}$$

Smaller $$\Delta T_s$$ places where it is very wet (extra energy from darker surface goes into evaporation)

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Effect of changing land surface properties on surface temperature energy flux potential

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Albedo:

\[ \Delta \chi \text{ per 4% darkening of albedo} \]

Direction of anomalous energy flow

Anomalous energy divergence in the atmosphere

Energy flux potential \( \chi \)

Anomalous energy flow \textbf{away from blue} regions \textbf{towards red} regions

Laguë et al. (in prep)
Effect of changing land surface properties on energy flux potential

Albedo:

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Anomalous energy flow away from blue regions towards red regions
Effect of changing land surface properties on energy flux potential

Albedo:

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Direction of anomalous energy flow

Land gets darker:

1. Energy flows *away* from land, towards oceans

2. Most anomalous energy flows away from big landmasses in the sub-tropics, where albedo leads to the most extra energy

Laguë et al. (in prep)
Effect of changing land surface properties on **surface temperature**

Evaporative resistance:

\[ \Delta T_s \text{ per } 50 \text{ s/m increase in evaporative resistance} \]

- **albedo**
  - Directly modifies how much energy the land absorbs

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    (no direct effect on total energy in the land system)

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Effect of changing land surface properties on surface temperature

Evaporative resistance:

$\Delta T_s$ per 50 s/m increase in evaporative resistance

- Increase evaporative resistance
- Less latent heat flux
- All else equal, should warm
- But how much it warms varies with location

Laguë et al. (2019)
Effect of changing land surface properties on surface temperature

Evaporative resistance:

$$\Delta T_s \text{ per 50 s/m increase in evaporative resistance}$$

Change in temperature [K]

Laguë et al. (2019)
Effect of changing land surface properties on surface temperature

Evaporative resistance:

$\Delta T_s$ per 50 s/m increase in evaporative resistance

No $\Delta T_s$ in places that have no water to evaporate in the first place

Change in temperature [K]

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Evaporative resistance:

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Largest \( \Delta T_s \) aren’t in the tropics

Laguë et al. (2019)
Effect of changing land surface properties on surface temperature

Evaporative resistance:

\[ \Delta T_s \text{ per } 50 \text{ s/m increase} \]

Change in temperature [K]
Evaporative resistance changes partitioning between sensible & latent heat

\[ \delta \text{Evap Frac} / \delta 50 \text{ [s/m]} r_s \]
Drier lower troposphere leads to a reduction in low cloud cover

\[ \uparrow \text{resistance} = \downarrow \text{evaporative fraction} \]

\[ \downarrow \text{evaporative fraction} = \downarrow \text{low clouds} \]
Less low clouds means more sun can reach the ground.
Extra shortwave heating of the surface leads to even bigger temperature responses

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\[ \downarrow \text{evaporative fraction} = \downarrow \text{low clouds} \]

\[ \downarrow \text{low clouds} = \uparrow \text{sun reaching ground} \]

\[ \uparrow \text{sun reaching ground} = \uparrow \text{surface } T \]
Extra shortwave heating of the surface leads to even bigger temperature responses

Isolating evaporative resistance highlights where clouds (in CAM5) are particularly sensitive to evaporation from the land surface.
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Separating the climate effects of albedo, evaporation, and roughness from historical vegetation change

Change in grassland and crop area
2000-1850

More trees now
Fewer trees now
% of gridcell
Separating the climate effects of albedo, evaporation, and roughness from historical vegetation change

Take historical vegetation change from CLM (2000 vs 1850)

Laguë et al. *In prep.*
Separating the climate effects of albedo, evaporation, and roughness from historical vegetation change

Take historical vegetation change from CLM (2000 vs 1850)

Impose the associated change in a **single** surface property in SLIM

Δ albedo

Δ evaporative resistance

Δ roughness

Laguë et al. *In prep.*
Separating the climate effects of albedo, evaporation, and roughness from historical vegetation change

Take historical vegetation change from CLM (2000 vs 1850)

Impose the associated change in a **single** surface property in SLIM

Separate how much $\Delta T$ from historical vegetation comes from each surface property

$\Delta$ albedo

$\Delta$ evaporative resistance

$\Delta$ roughness

Laguë et al. *In prep.*
Separating the climate effects of albedo, evaporation, and roughness from historical vegetation change

Take historical vegetation change from CLM (2000 vs 1850)

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  Currently works with CESM 2.1

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• Stepping-stone between an aqua-planet and a full ESM
Summary

• SLIM: idealized land model that can couple to a modern ESM (specifically CESM)
  Currently works with CESM 2.1

• Stepping-stone between an aqua-planet and a full ESM

• Useful for:
  • Isolating the effects of individual land surface properties on the Earth system
  • Any time you don’t want a full-complexity land model, but just need a land surface to conserve energy & water at the bottom of the atmosphere

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