Threshold behavior in surface response to mid-latitude afforestation

CESM-LMWG Meeting
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Goal:

Explore how amount of trees in mid-latitudes:

- impacts the local energy budget
- modifies cloud cover
- influences global circulation
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Explore how amount of trees in mid-latitudes:

• impacts the local energy budget
• modifies cloud cover
• influences global circulation

How does the response scale with the amount of trees added?
Plant-atmosphere interactions: location matters
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Tropics

H₂O dominated
Forests cool
Plant-atmosphere interactions: location matters

**Tropics**
- $\text{H}_2\text{O}$ dominated
- Forests *cool*

**Boreal**
- Albedo dominated
- Forests *warm*
Plant-atmosphere interactions: location matters

Tropics

H₂O dominated
Forests cool

Mid-latitudes

Albedo dominated
Forests warm

Boreal
Plant-atmosphere interactions: location matters

Tropics

H$_2$O dominated
Forests *cool*

Mid-latitudes

H$_2$O or albedo?

Boreal

Albedo dominated
Forests *warm*

H$_2$O

(Bonan 2008)
Plant-atmosphere interactions: location matters

Tropics: \( \text{H}_2\text{O} \) dominated

Mid-latitudes: \( \text{H}_2\text{O} \) or albedo?

Boreal: Albedo dominated

(Albedo dominated: Bonan 2008)
Model experiments:
Increase tree cover from 30°N – 60°N

- CESM 1.3
  - CAM5 atmosphere,
  - CLM 4.5 land (with carbon cycle)
  - CICE4 dynamic sea ice
  - Slab ocean

- 50 year simulations (20 years of spin up)
Model experiments:
Increase tree cover from 30°N – 60°N

5 simulations:
- Present day forest cover
- 4 experiments increasing forest cover by ~3,500,000 km² each (50%, 100% grasslands and 50%, 100% agricultural lands)
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More sun is absorbed over land as tree area increases.
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Δ Absorbed Shortwave (Land Area, 30°N to 60°N)

More clouds

W/m²

Grass50  Grass100  GrassAgr150  GrassAgr200
More sun is absorbed over land as tree area increases

$\Delta$ Absorbed Shortwave (Land Area, 30°N to 60°N)

More clouds

More energy absorbed
(darker surface, less clouds)

Grass50  Grass100  GrassAgr150  GrassAgr200
Outgoing surface energy (land area, 30°N to 60°N)

$\Delta$ Latent Heat ($H_2O$)
More trees = more evapotranspiration

\[ \Delta \text{Latent Heat (H}_2\text{O)} \]
More trees = more evapotranspiration
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Δ Latent Heat (H₂O)

<table>
<thead>
<tr>
<th></th>
<th>Grass50</th>
<th>Grass100</th>
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<tbody>
<tr>
<td>W/m²</td>
<td>0.5</td>
<td>1.5</td>
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The diagram illustrates the increase in latent heat (H₂O) release with more trees. The chart shows a higher value for Grass100 compared to Grass50, indicating a greater evapotranspiration rate with increased tree coverage.
Threshold: increasing tree cover doesn’t increase water fluxes

\[ \Delta \text{Latent Heat (H}_2\text{O)} \]

![Graph showing the comparison of latent heat for different grass cover types.]
Threshold: increasing tree cover doesn’t increase water fluxes
Threshold: increasing tree cover doesn’t increase water fluxes (despite absorbing more solar energy)
Threshold: $\Delta$ evapotranspiration depends on water availability
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Evapotranspiration Increasing

$\Delta$ Latent Heat (H$_2$O)

Water limited experiments
Part of the unaccounted for energy: outgoing longwave radiation
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Δ Latent Heat (H₂O), Longwave Radiation, Sensible Heat

Water limited experiments
Part of the unaccounted for energy: sensible heat

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Δ Latent Heat (H₂O), Longwave Radiation, Sensible Heat

Water limited experiments

Grass50  Grass100  GrassAgr150  GrassAgr200

LH  OLR  SH

W/m²
Part of the unaccounted for energy: sensible heat

Δ Latent Heat (H₂O), Longwave Radiation, Sensible Heat

More longwave + sensible heat = increased temperatures
Change heat and water fluxes => change relative humidity
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When water is limiting, the troposphere dries.
Mid-latitude Response: 2 Regimes

Regime 1: Water available
- Energy goes out as water

Regime 2: Water limited
- Cloud cover decreases, surface warms
Regime 2: two pathways for energy absorption

Cloud response effect

Surface albedo effect

Cloud cover decreases, surface warms

Regime 2: Water limited
Summary

1. Increase mid-latitude forest cover: reach a threshold on water fluxes (latent heating)

2. Before water threshold, increased clouds compensate for darker surface. When water threshold is reached, more trees -> less clouds (troposphere dries)

3. Mid-latitudes absorb more solar energy **not only** because the surface gets darker (albedo effect), but also because cloud cover is reduced (more warming than water)
For a given change in energy transport, we get some shift in rain

Quantify this: what is the ΔITCZ for a given Δ energy transport?
\[ \frac{\Delta ITCZ}{\Delta AHT_{eq}} \]

Cam5  8.7°/PW
CMIP3  3.2°/PW
Cam3  2.3°/PW