Threshold behavior in surface response to mid-latitude afforestation

CESM-LMWG Meeting

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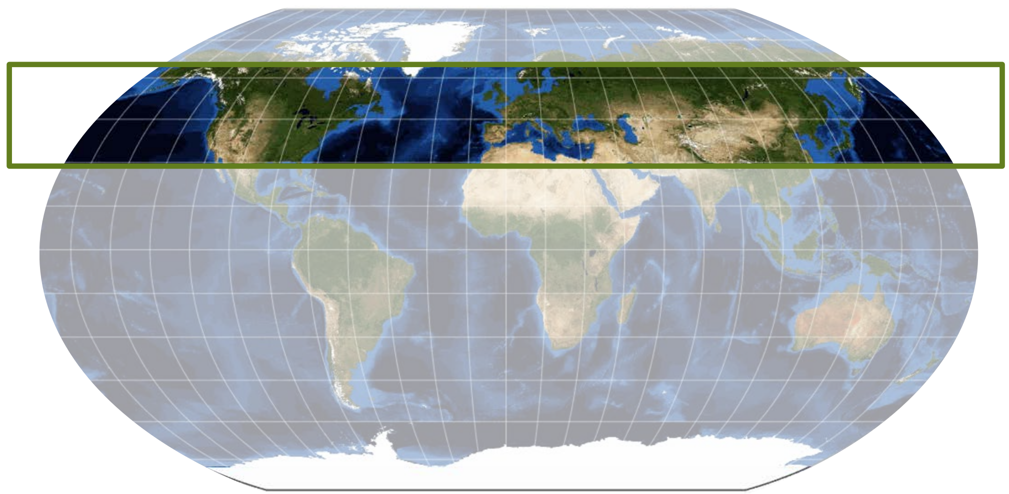
Goal:

Explore how **amount** of trees in mid-latitudes:

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



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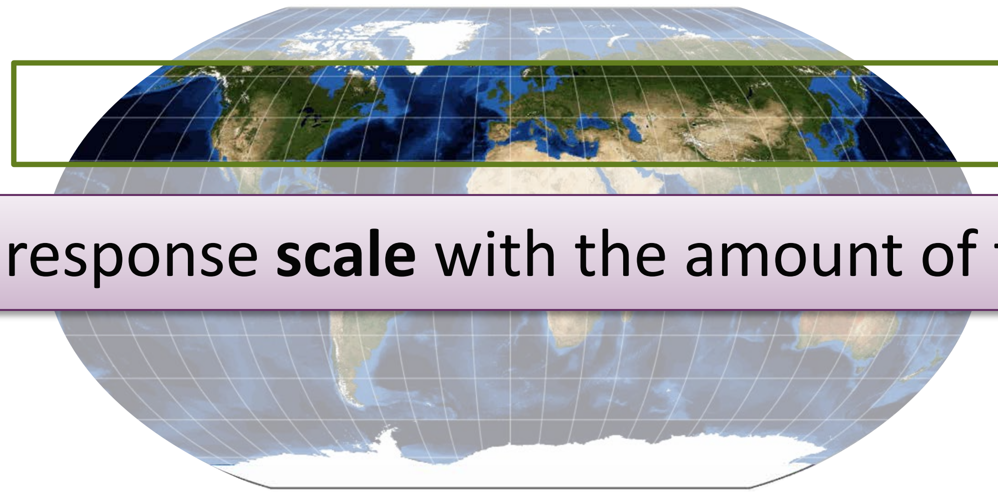

How does the response **scale** with the amount of trees added?

Plant-atmosphere interactions: location matters

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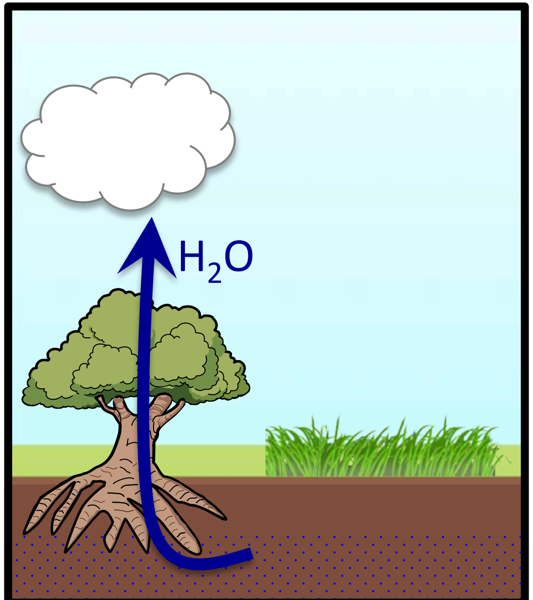
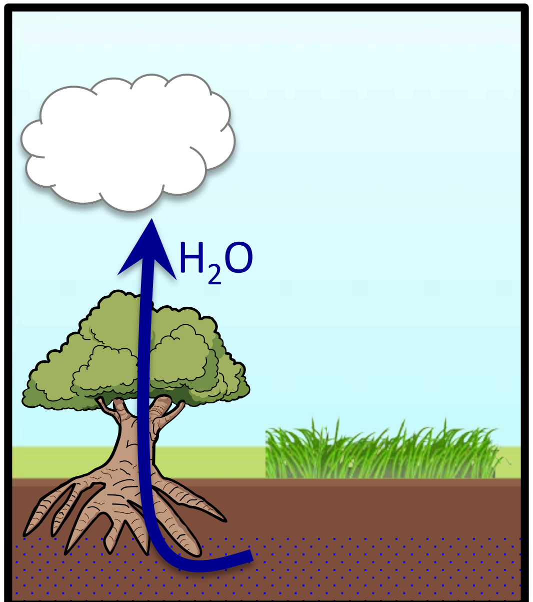
Tropics



H_2O dominated
Forests *cool*

Plant-atmosphere interactions: location matters

Tropics



H_2O dominated
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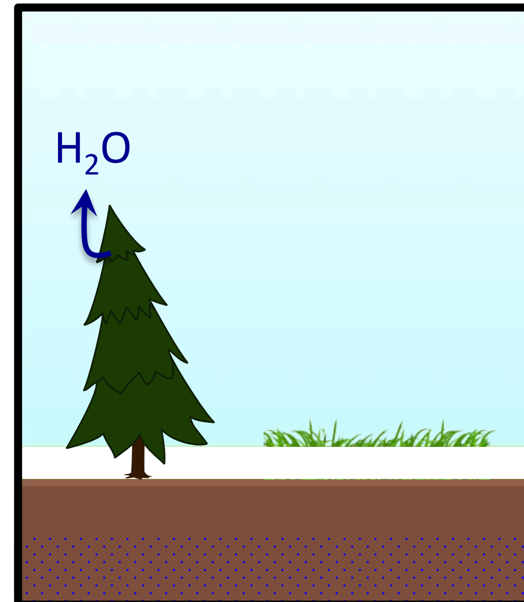
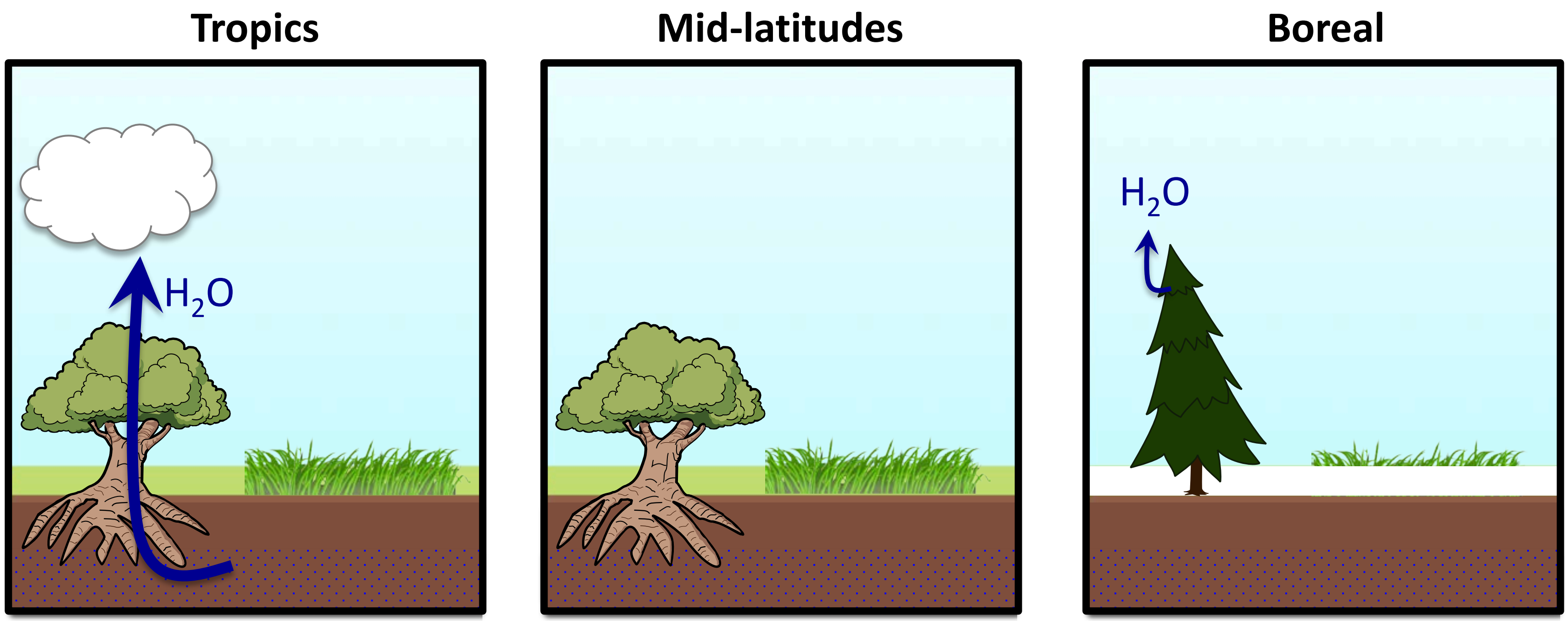
Boreal



Albedo dominated
Forests *warm*

Plant-atmosphere interactions: location matters



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Forests *cool*

Albedo dominated
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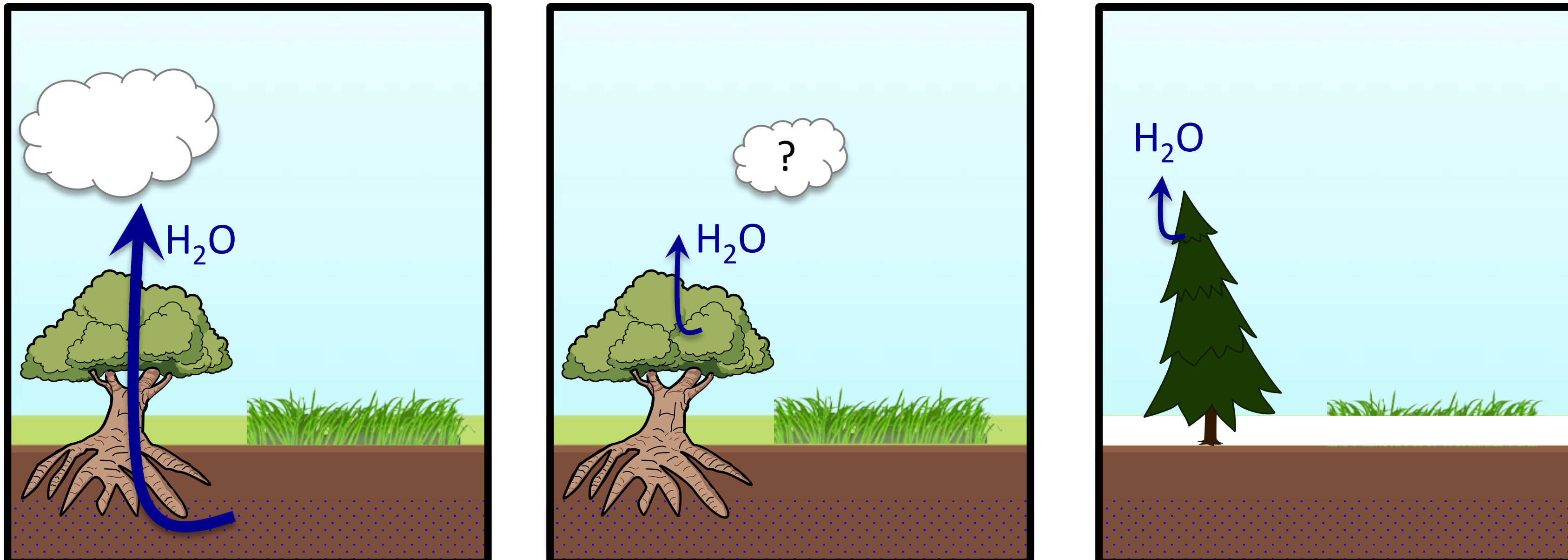


Tropics

H_2O dominated
Forests *cool*

Mid-latitudes

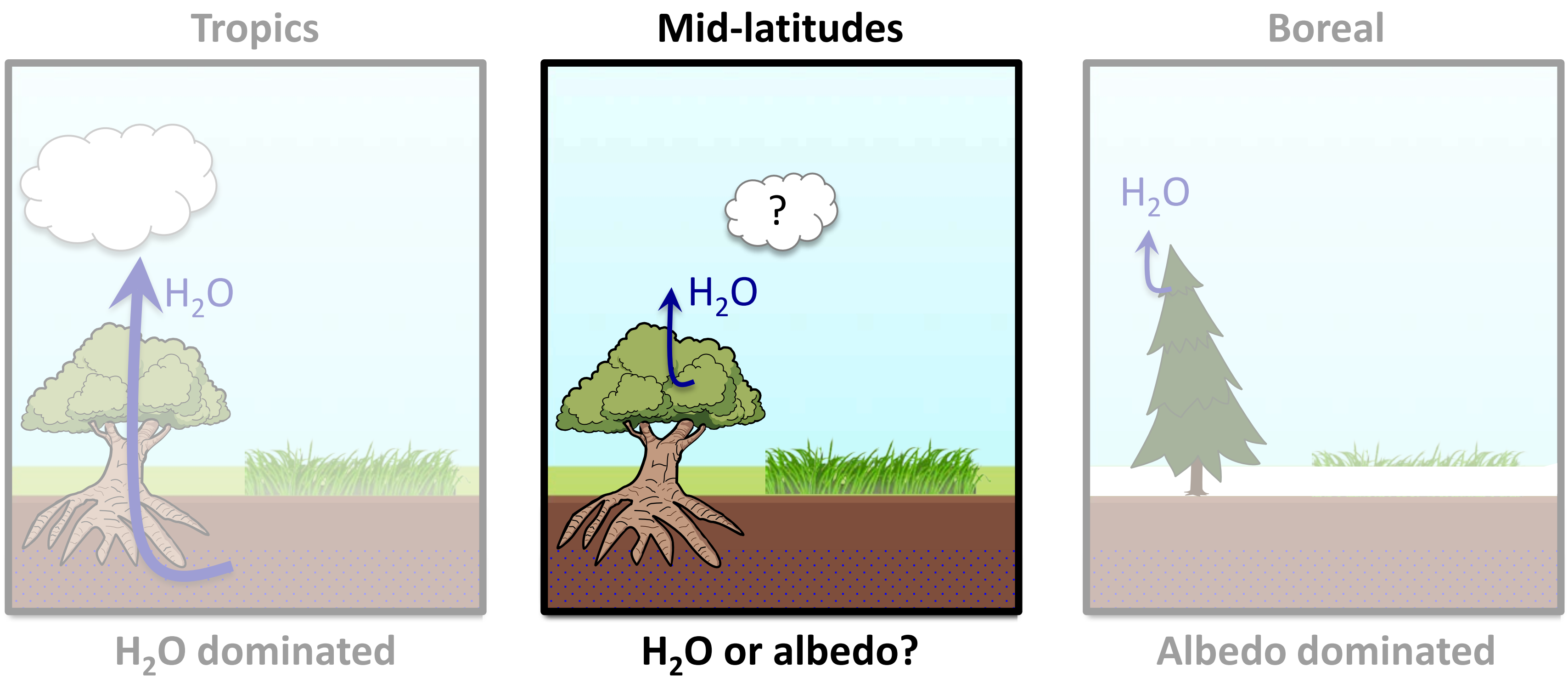
H_2O or albedo?

Boreal

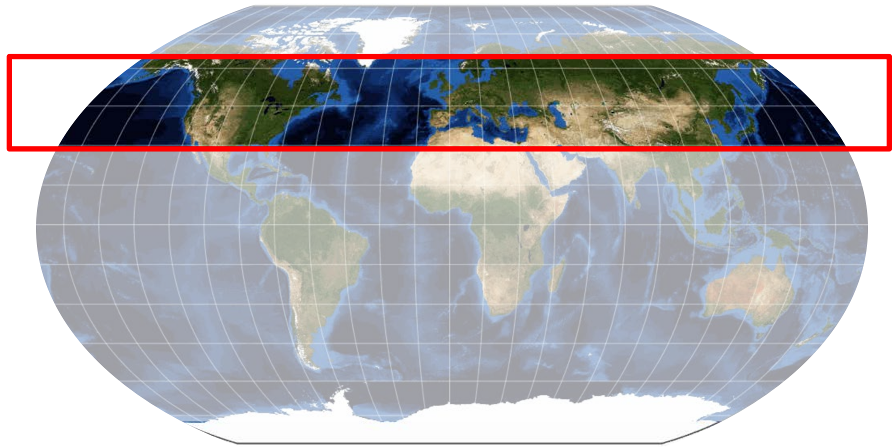
Albedo dominated
Forests *warm*

(Bonan 2008)

Plant-atmosphere interactions: location matters



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)

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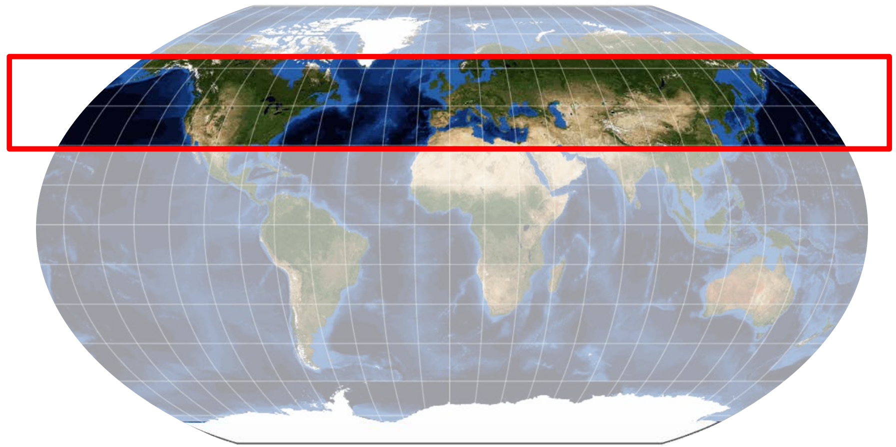
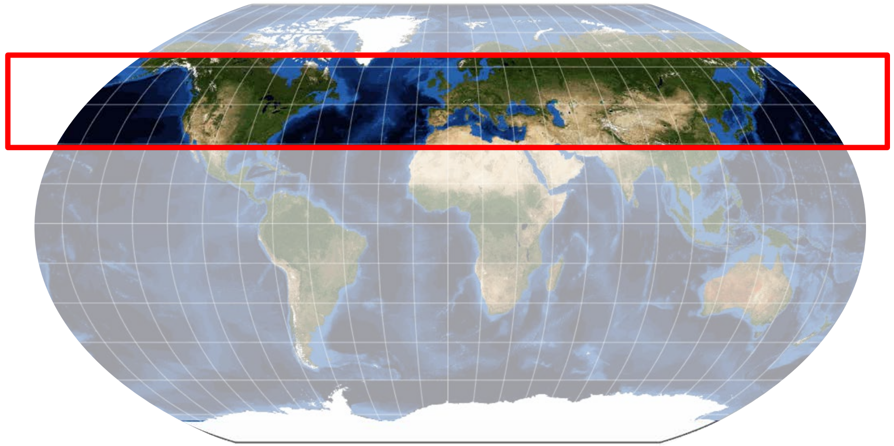


5 simulations:

- Present day forest cover
- 4 experiments increasing forest cover by ~3,500,000 km^2 each (50%, 100% grasslands and 50%, 100% agricultural lands)

Model experiments: Increase tree cover from 30°N – 60°N

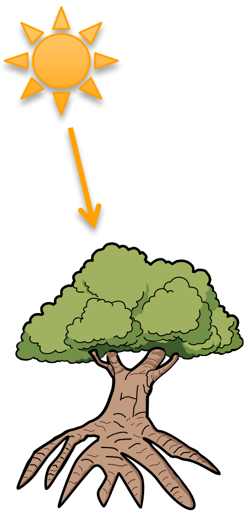


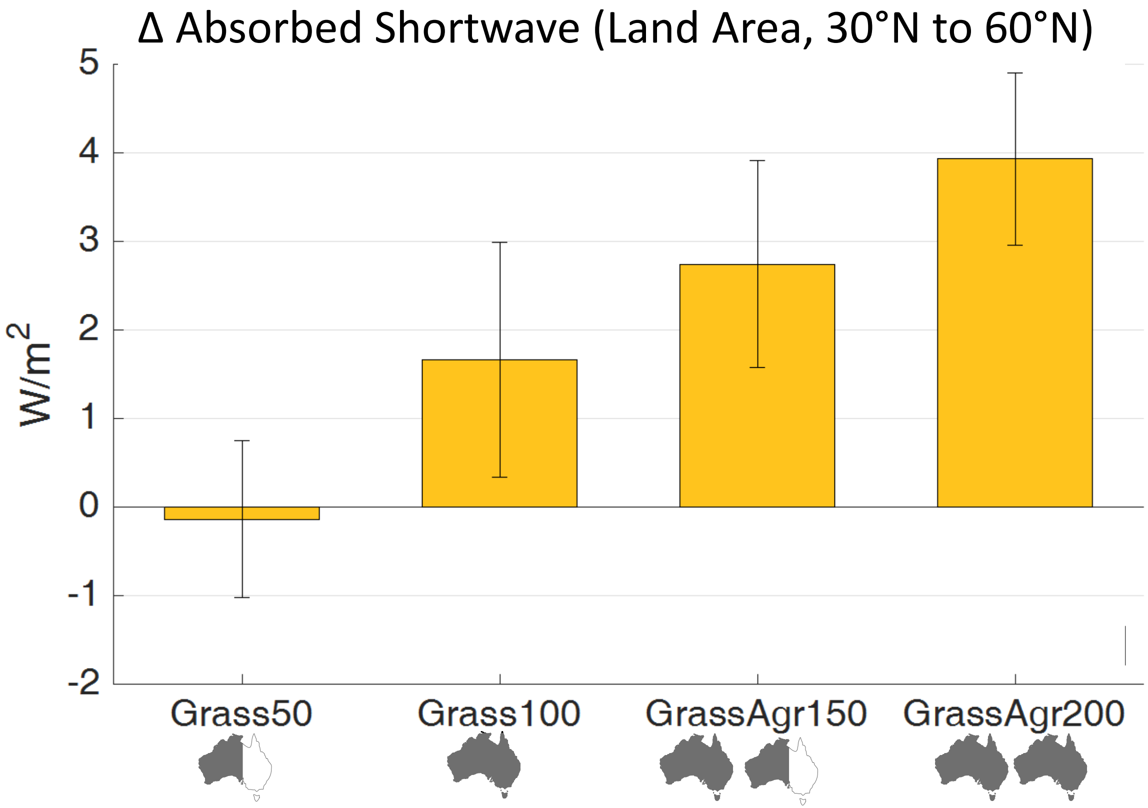
5 simulations:

- Present day forest cover
- 4 experiments increasing forest cover by ~3,500,000 km^2 each (50%, 100% grasslands and 50%, 100% agricultural lands)

~ half the size of Australia (lots of trees)

More sun is absorbed over land as tree area increases





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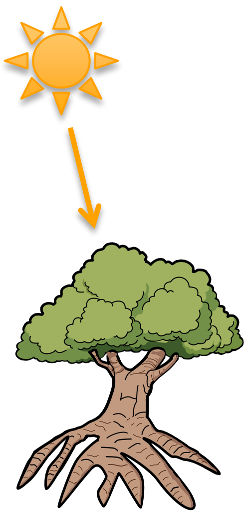

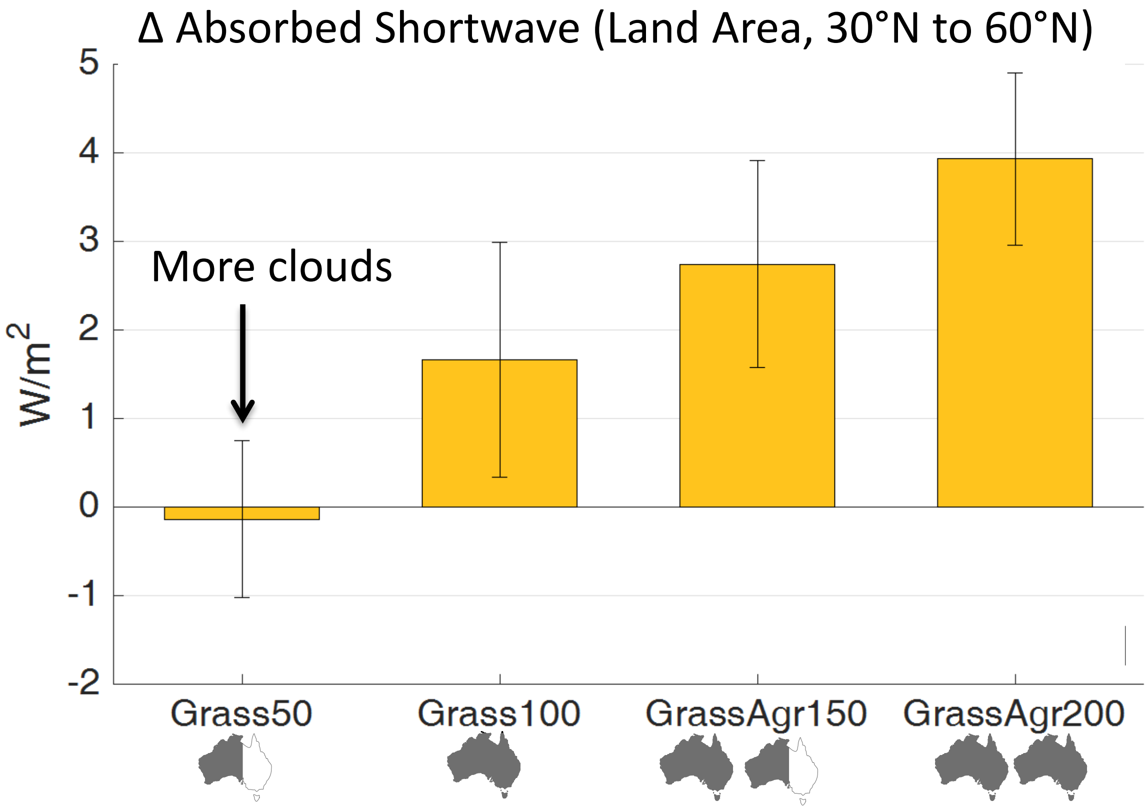

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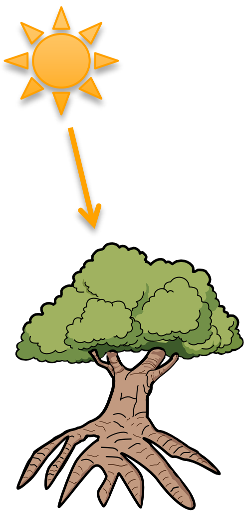
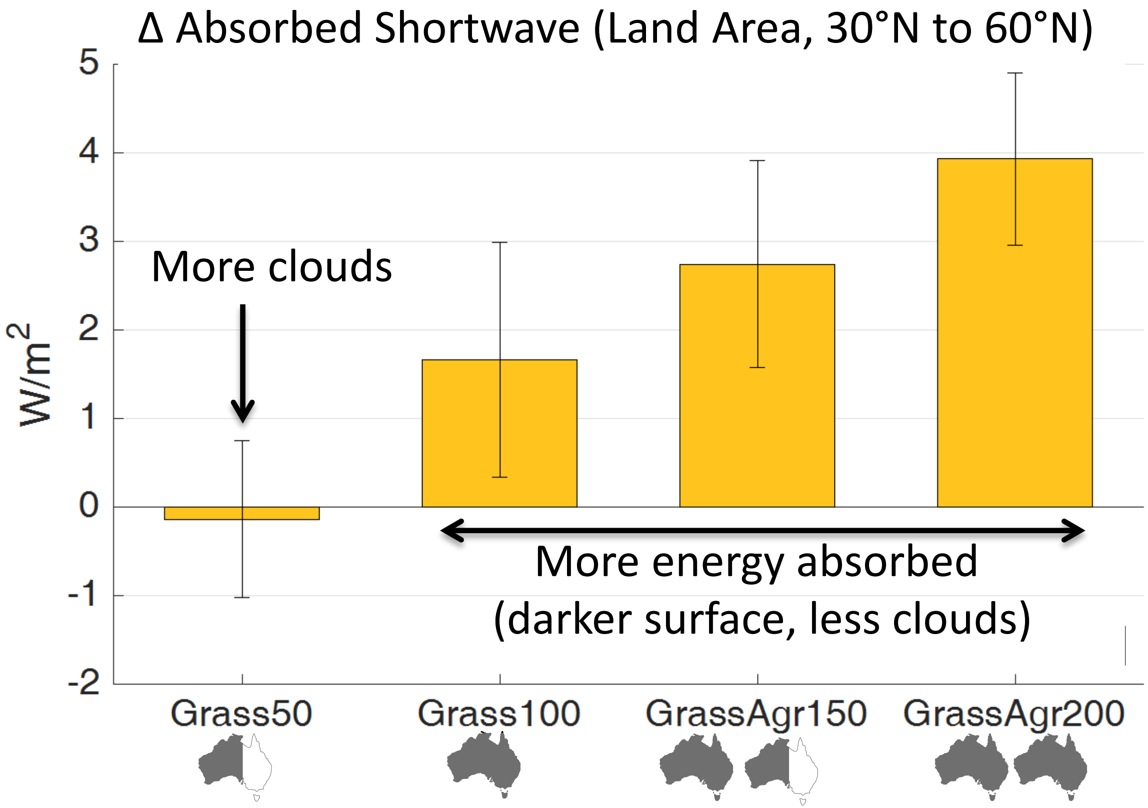
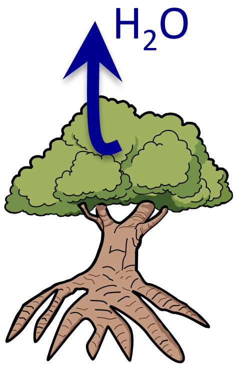




Outgoing surface energy (land area, 30°N to 60°N)



Δ Latent Heat (H_2O)

More trees = more evapotranspiration

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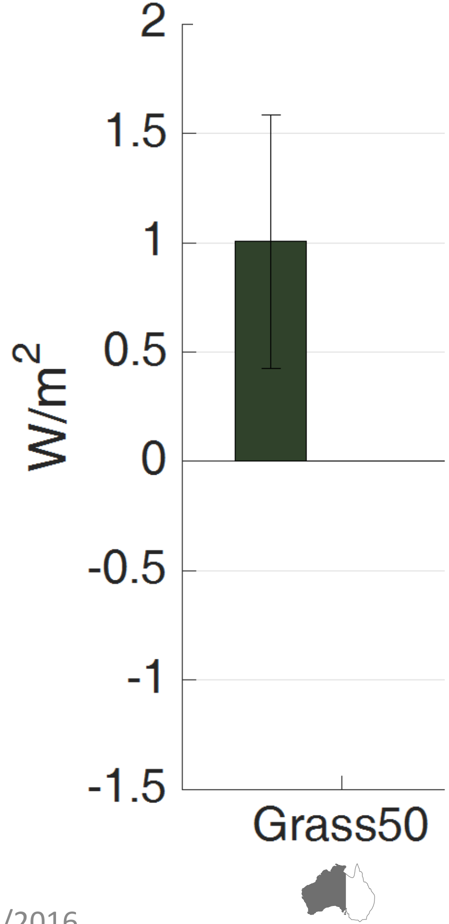

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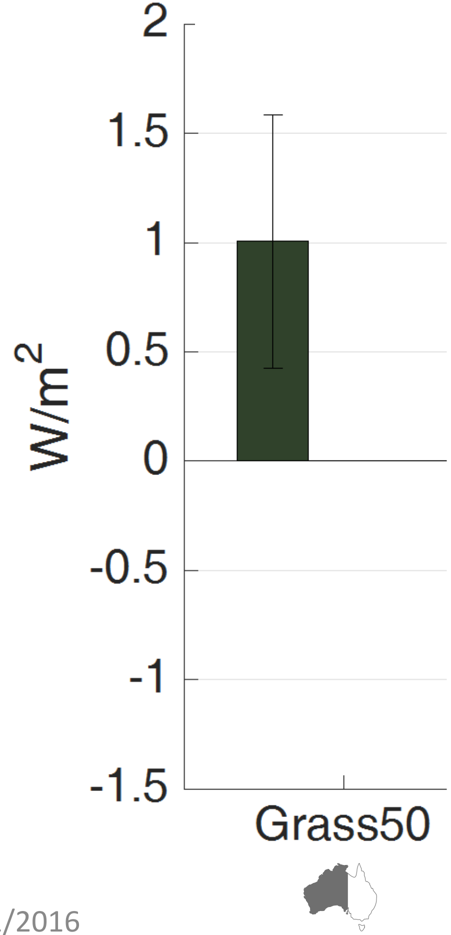

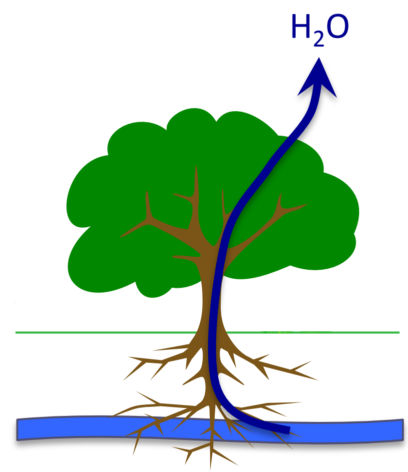

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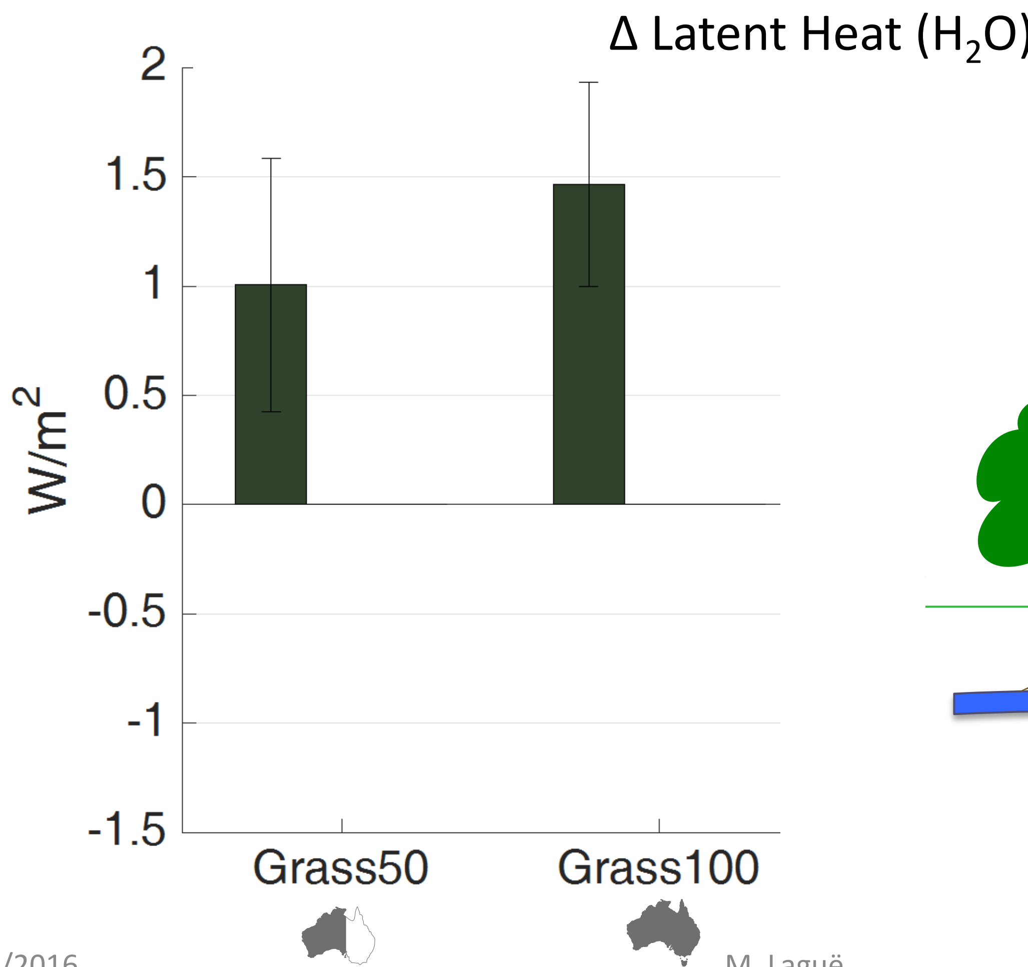
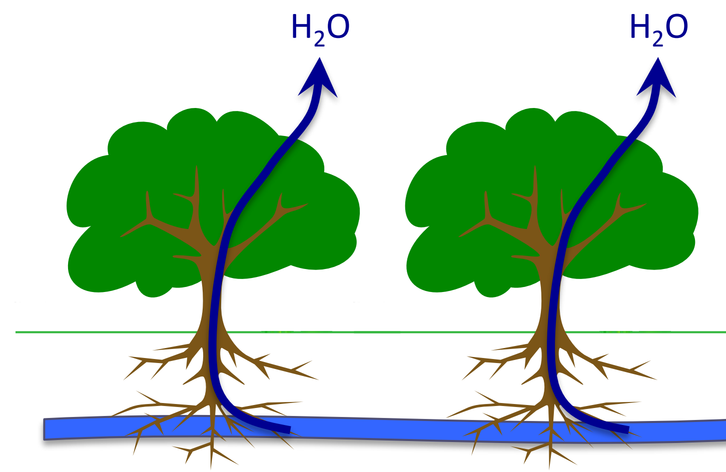
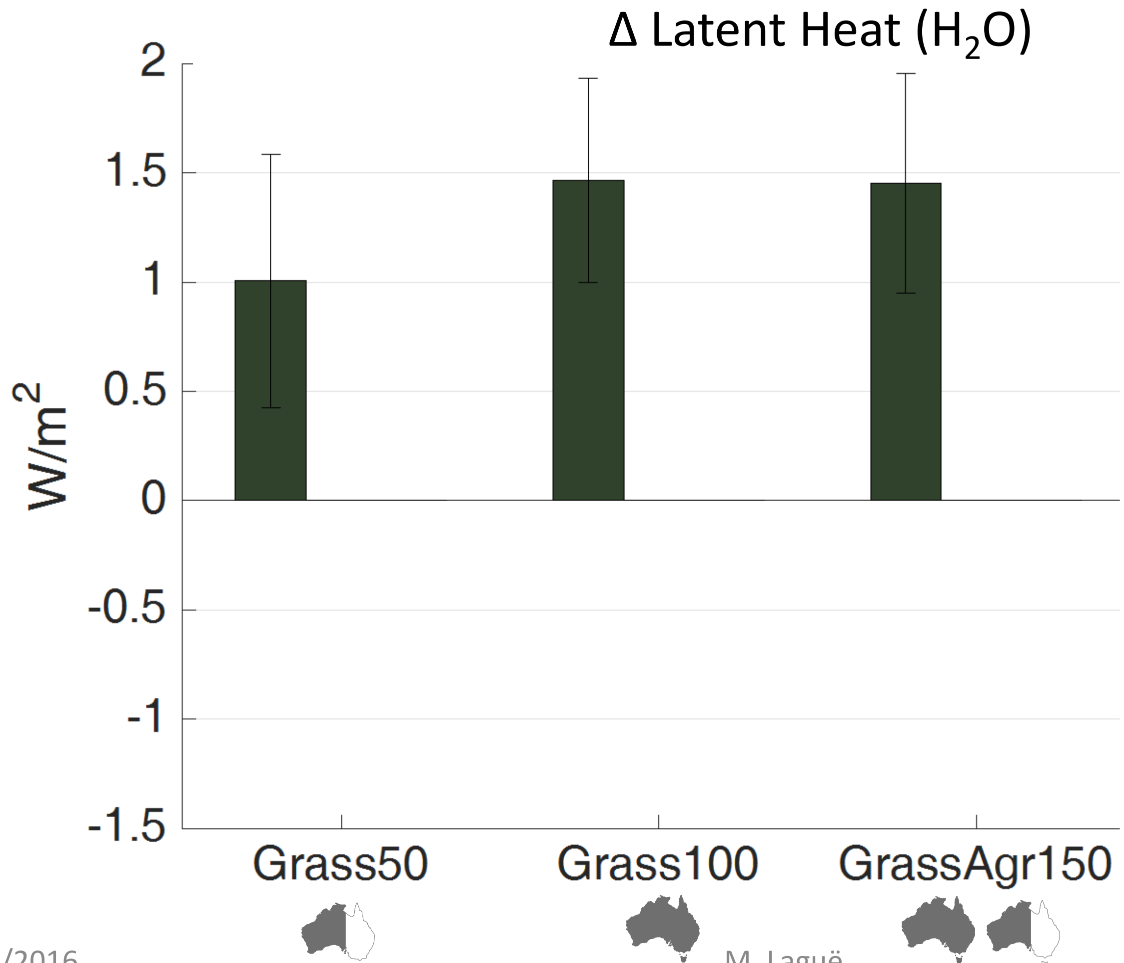




Threshold: increasing tree cover doesn't increase water fluxes



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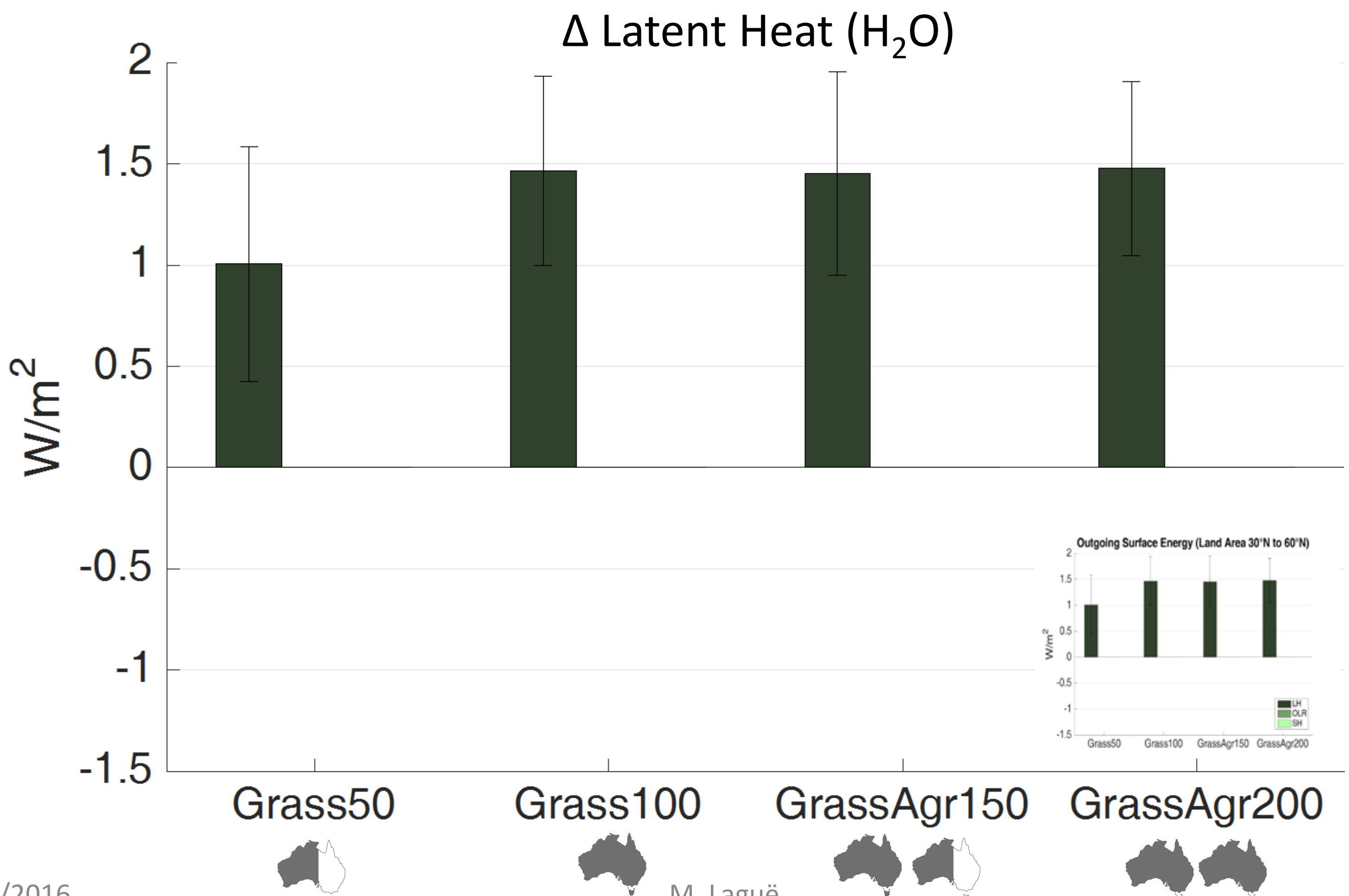
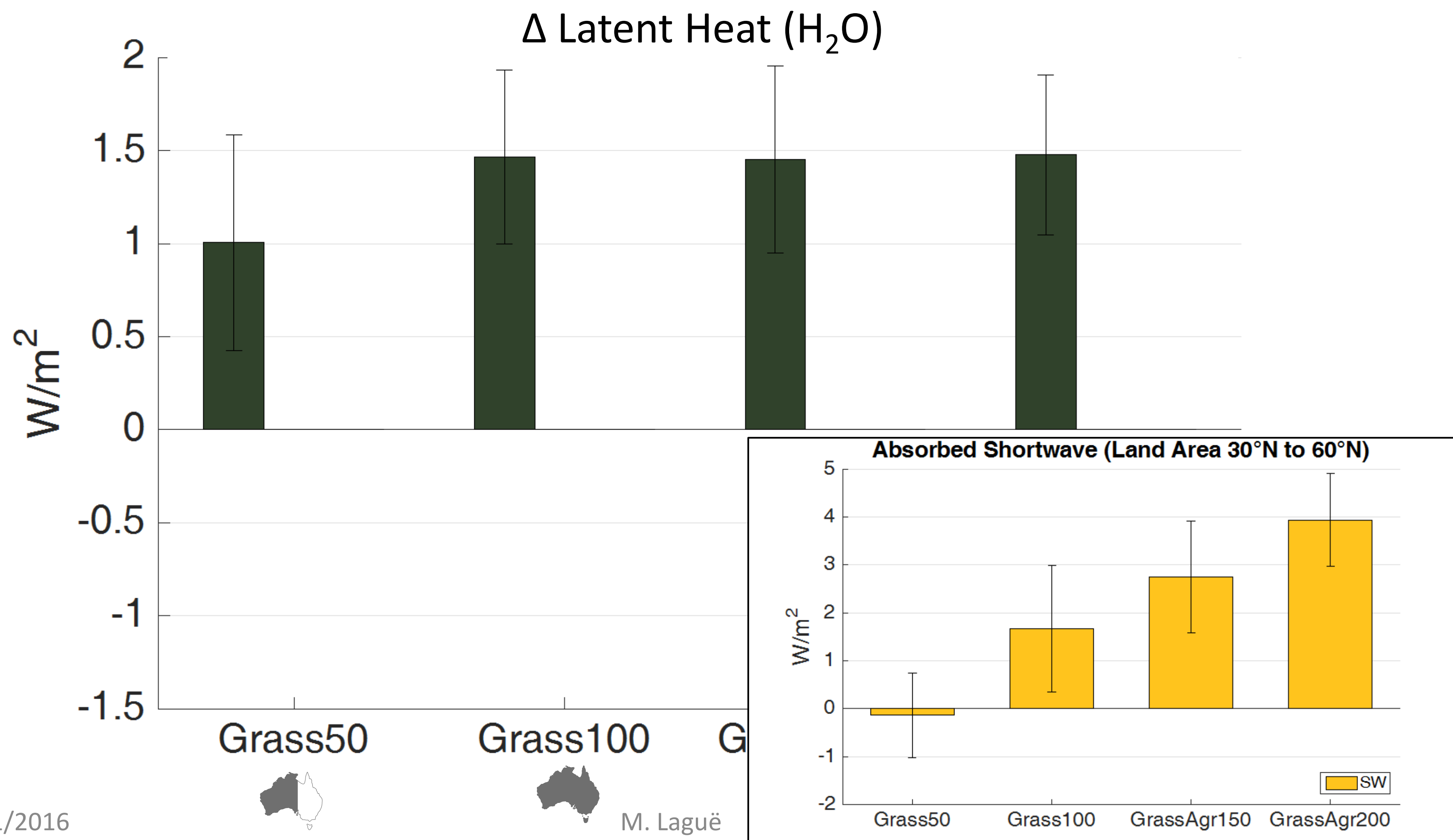
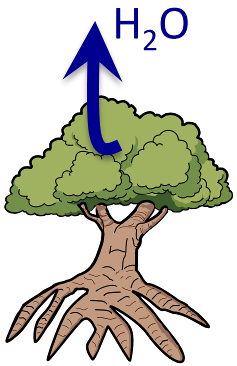


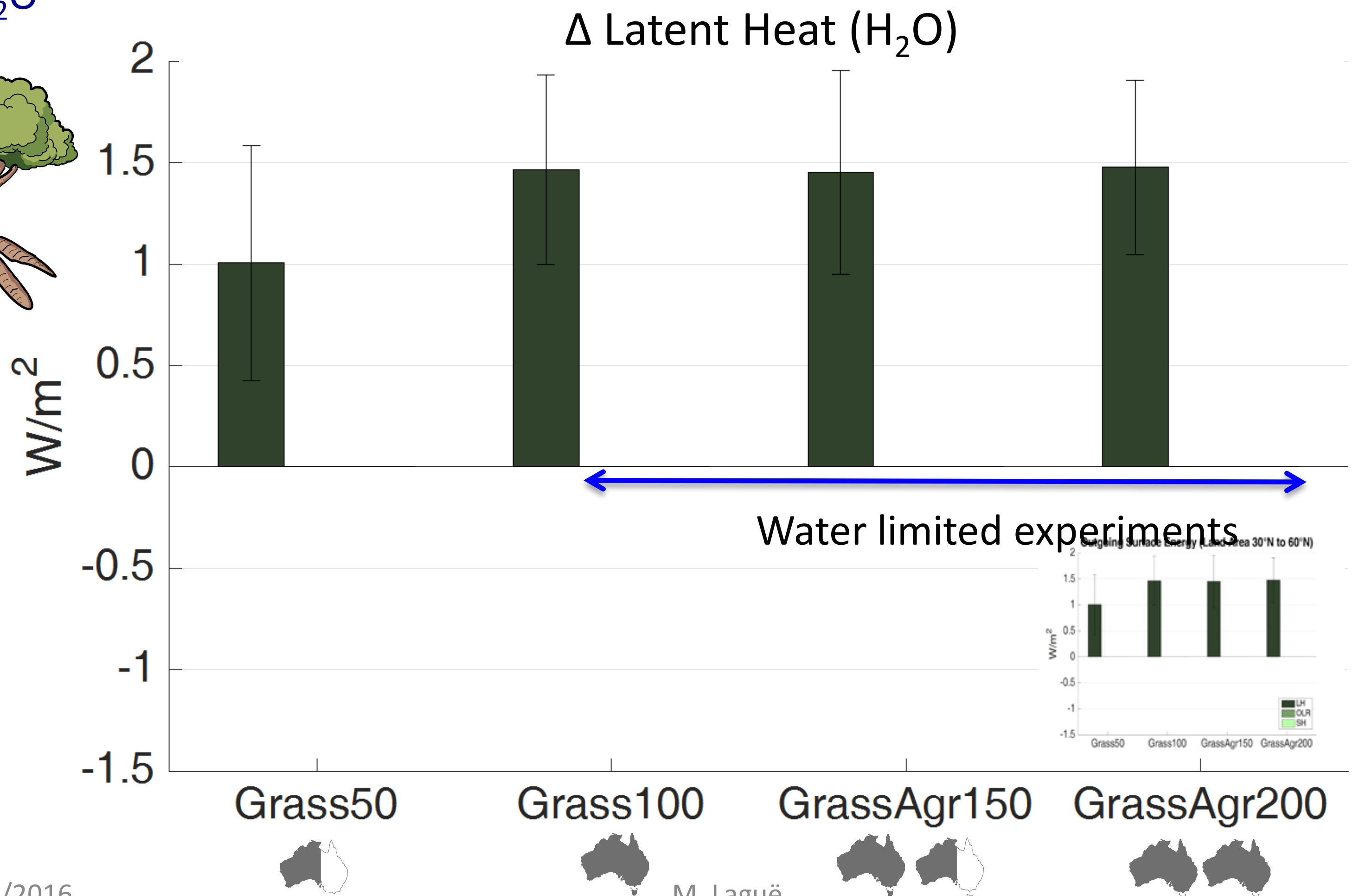
Threshold: increasing tree cover doesn't increase water fluxes

(despite absorbing more solar energy)



Threshold: Δ evapotranspiration depends on water availability





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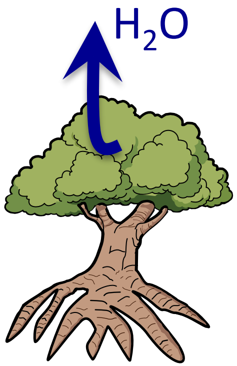
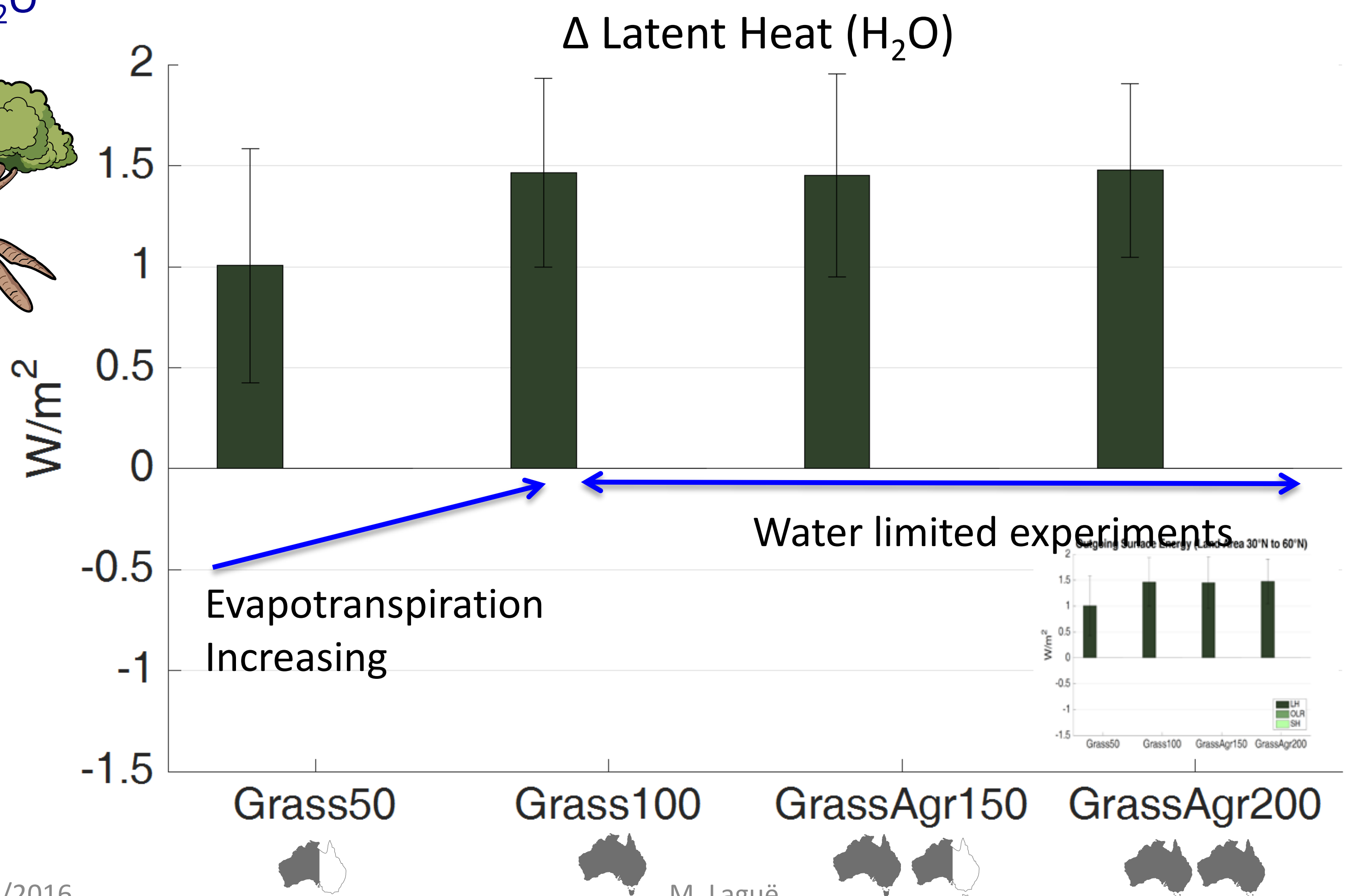
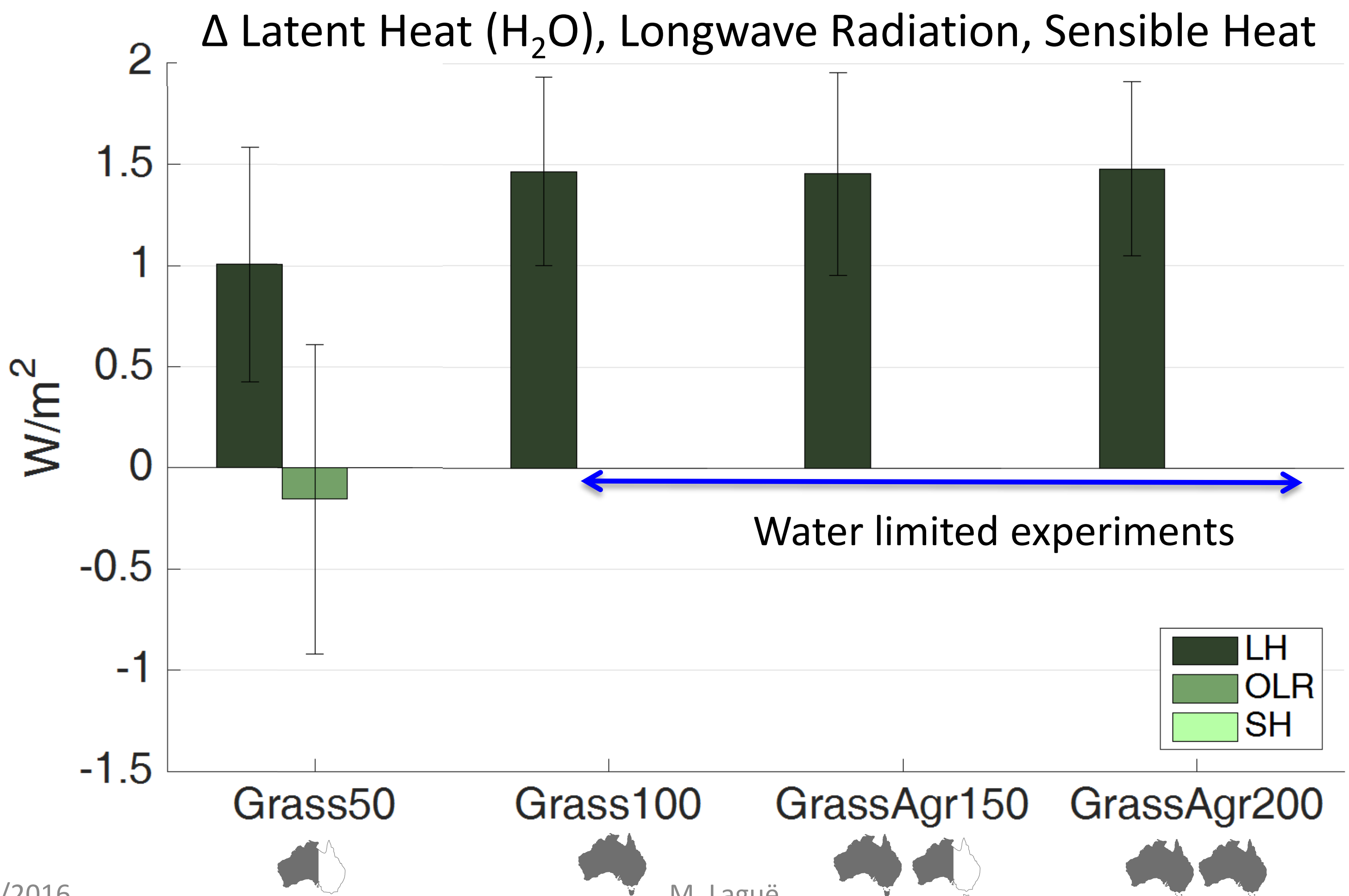




Part of the unaccounted for energy: outgoing longwave radiation



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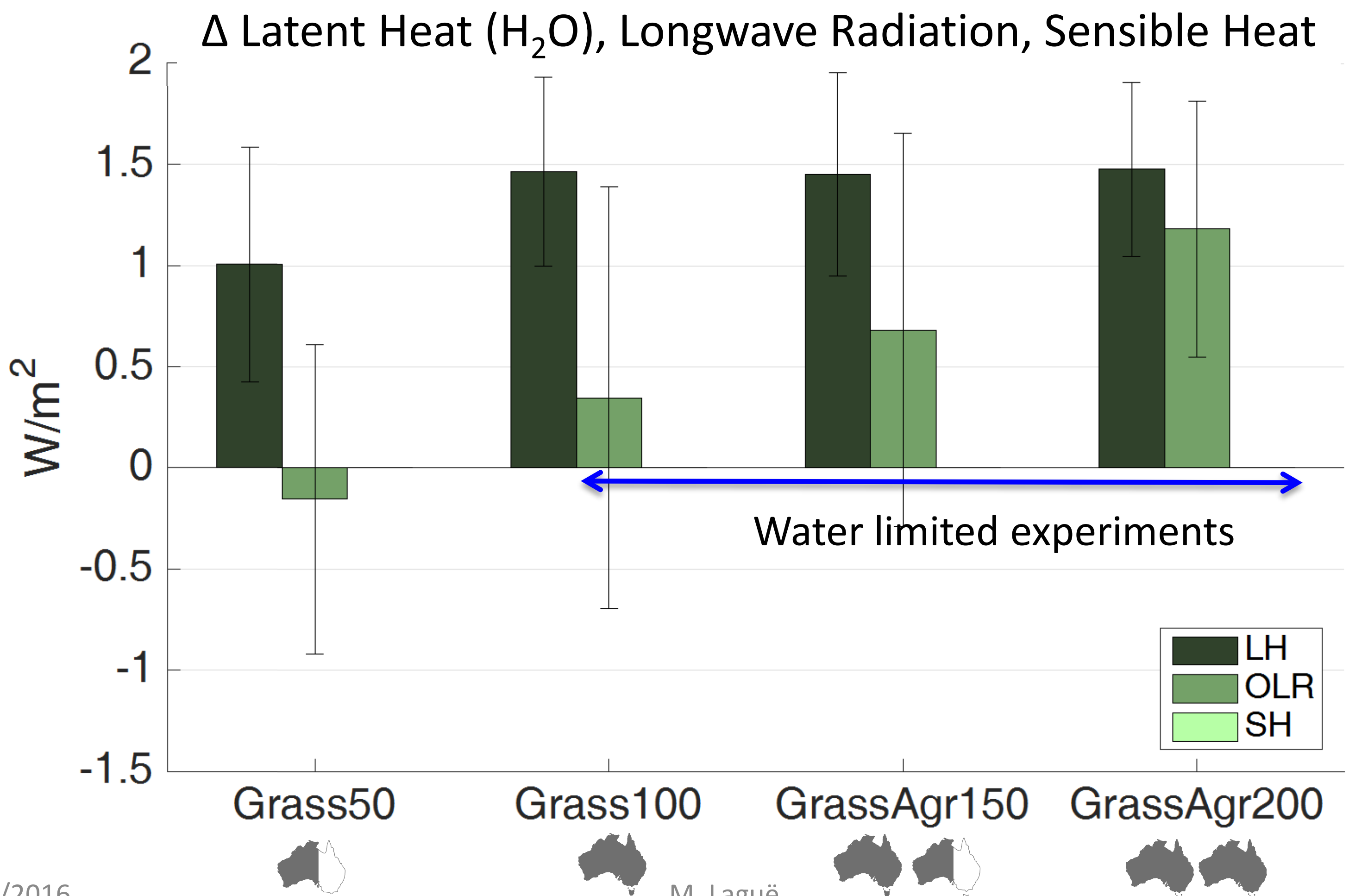
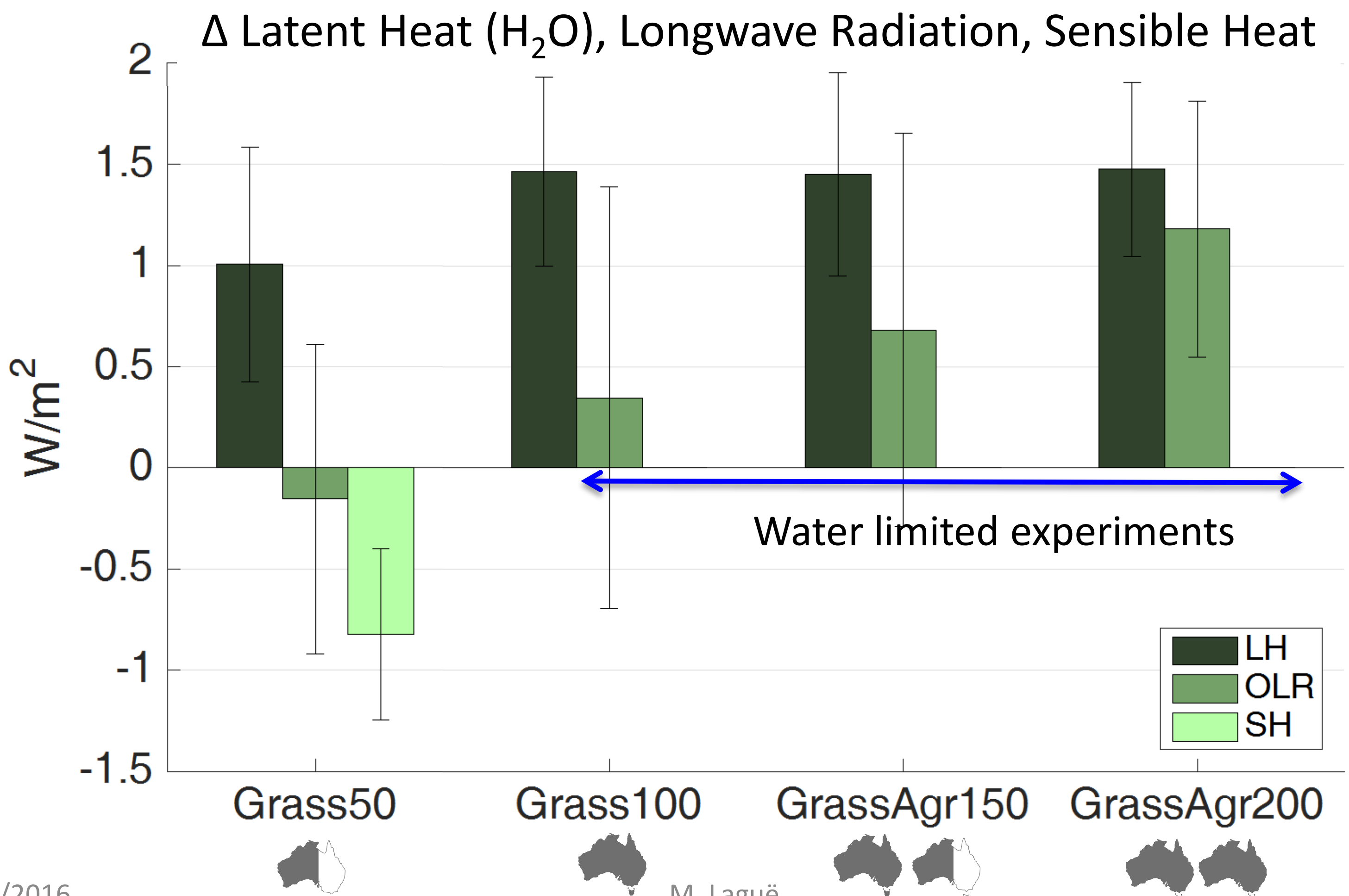


Part of the unaccounted for energy: sensible heat



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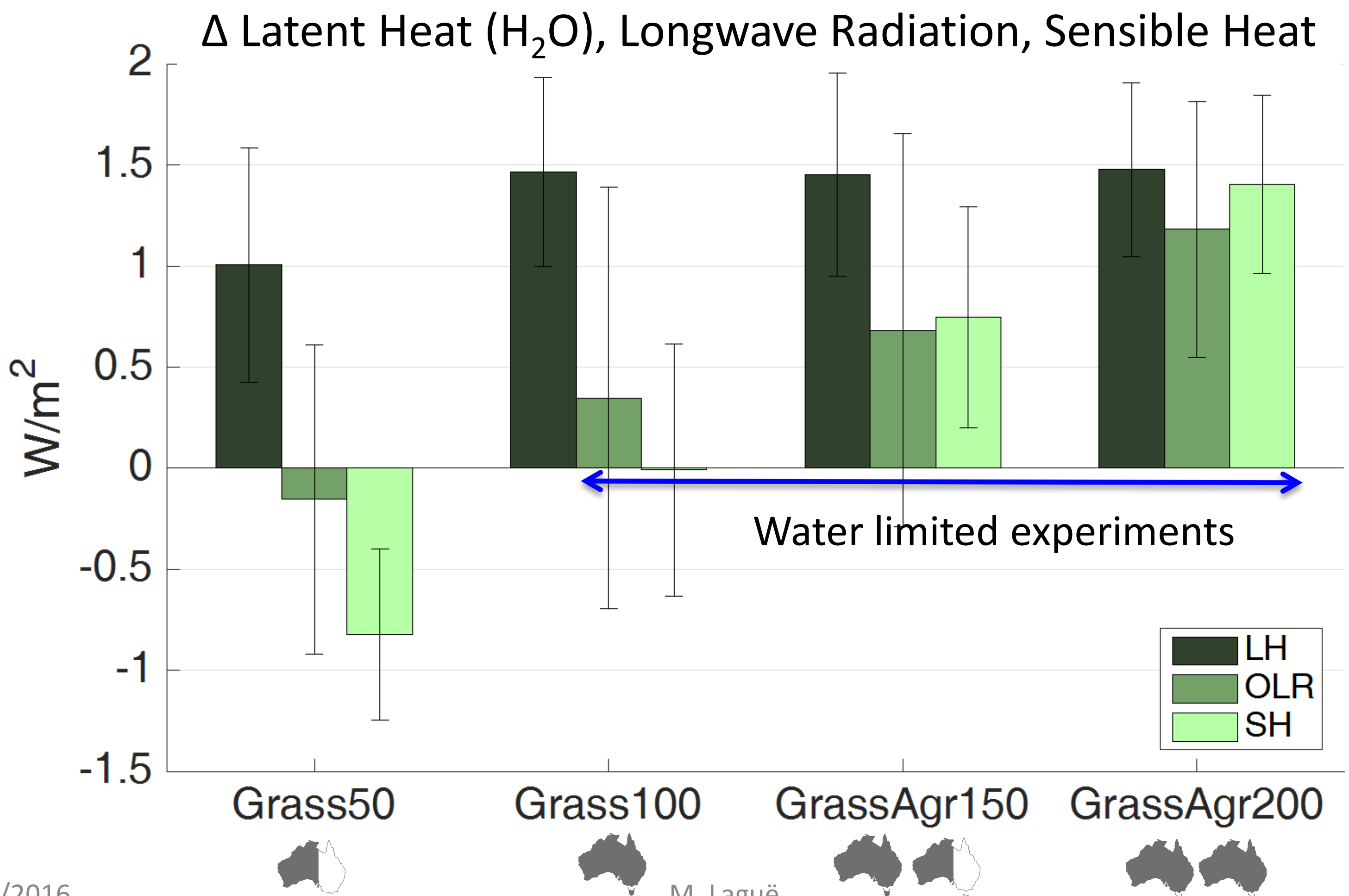

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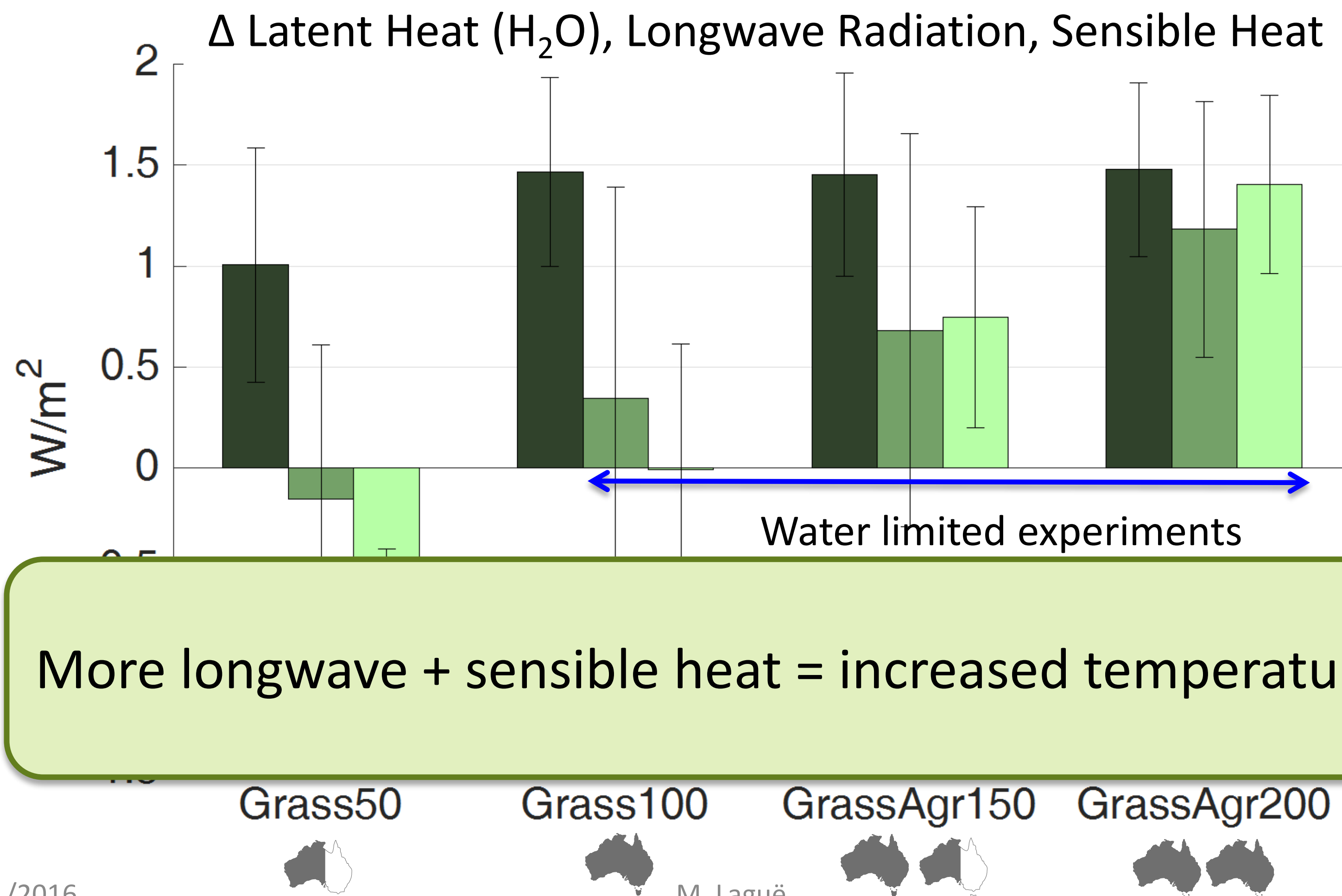
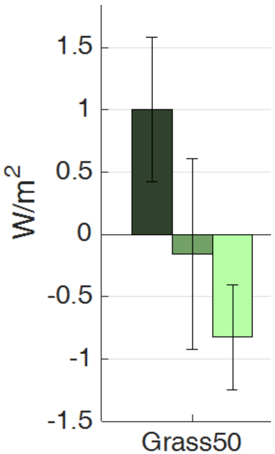
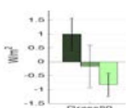
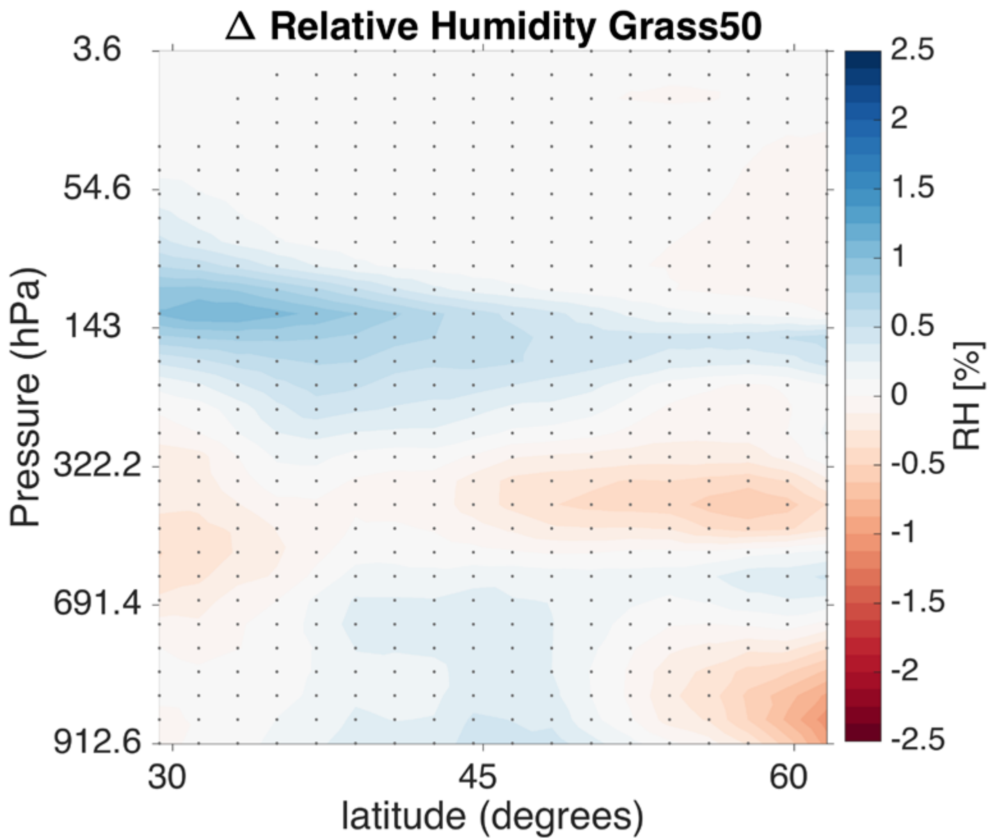


More longwave + sensible heat = increased temperatures

Change heat and water fluxes => change relative humidity







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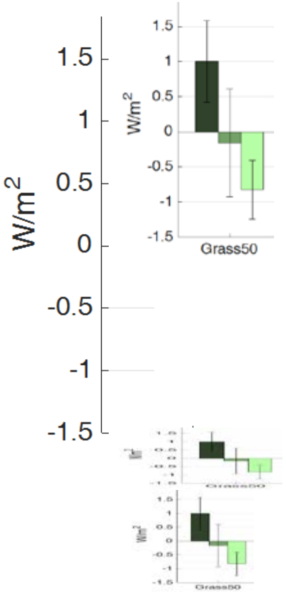
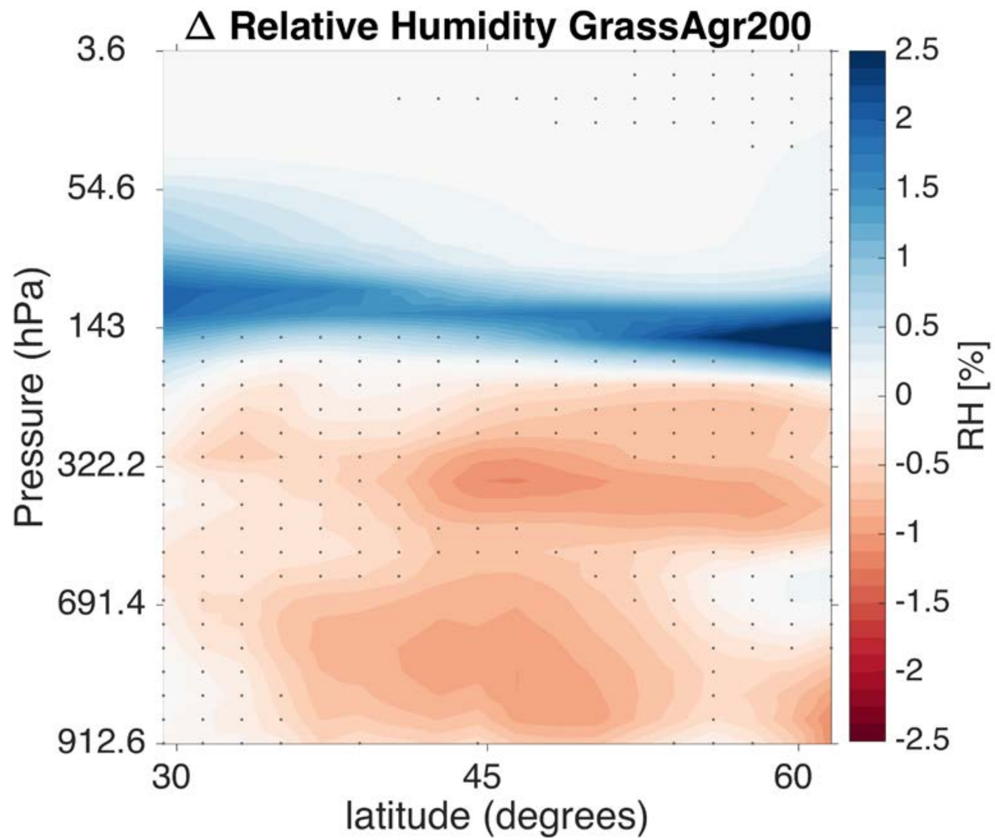
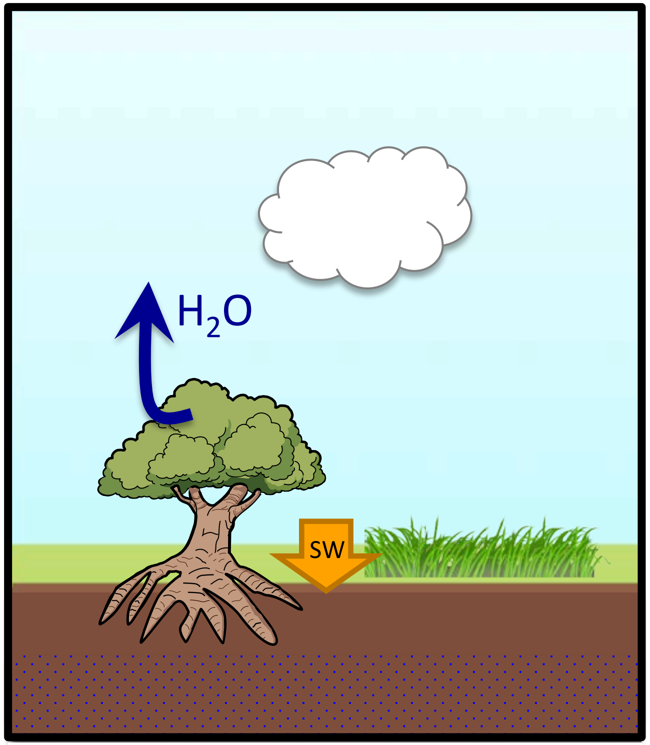




When water **is** limiting, the troposphere dries

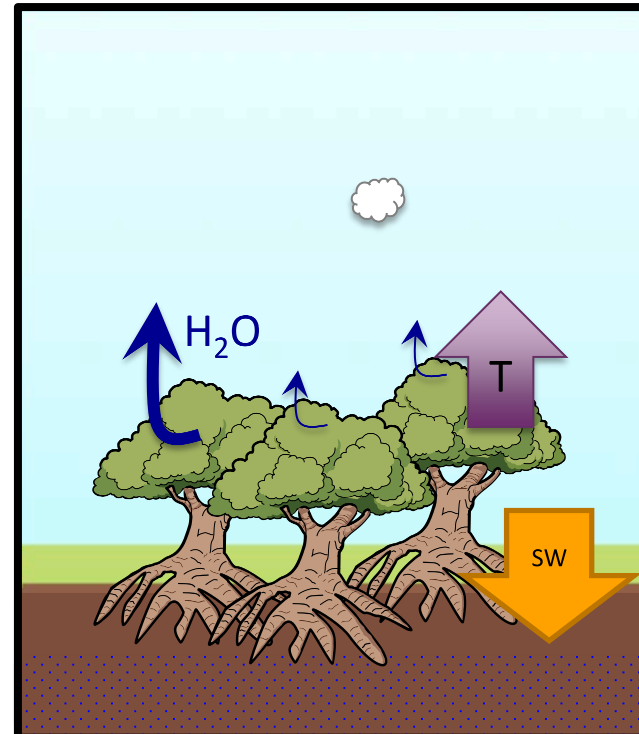
Mid-latitude Response: 2 Regimes

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

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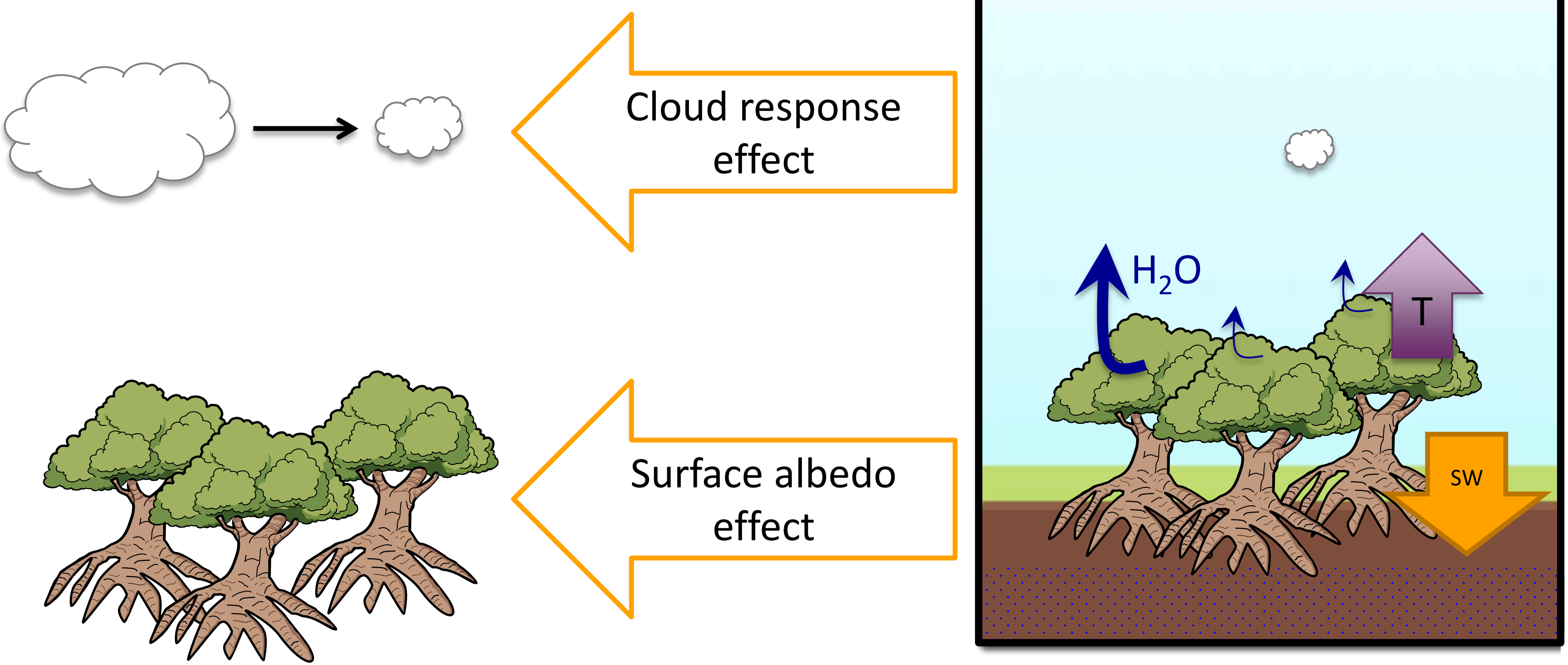


Cloud cover decreases, surface warms

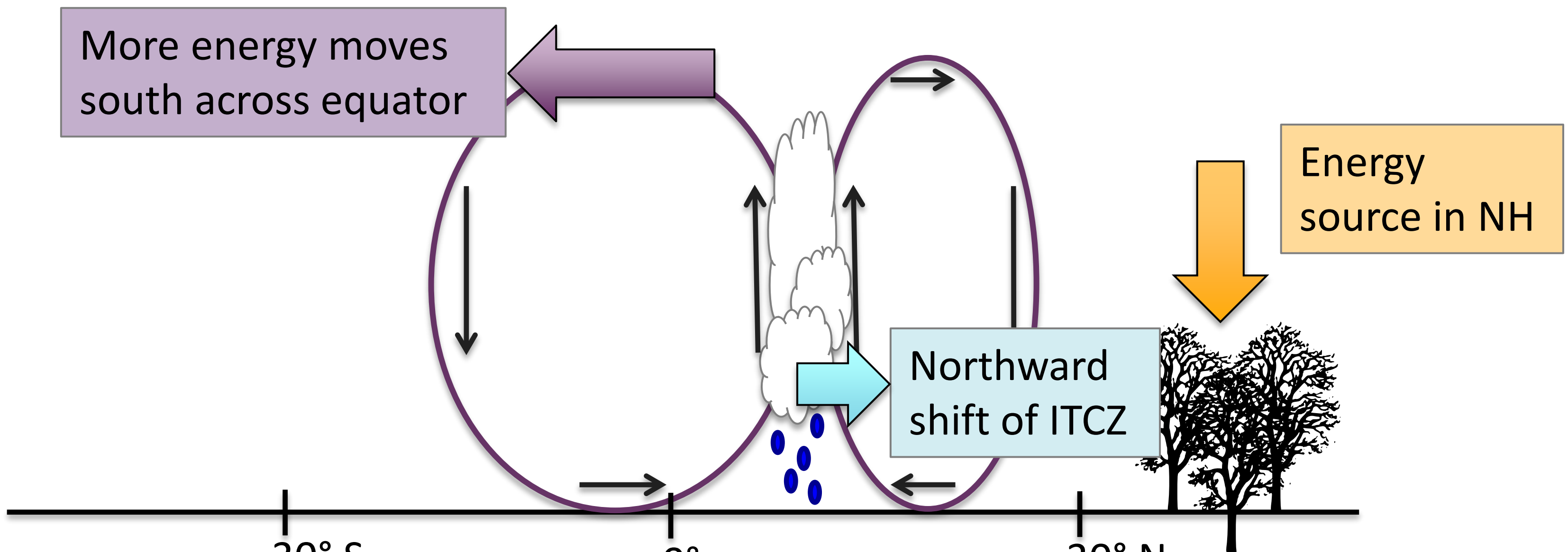
Summary

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

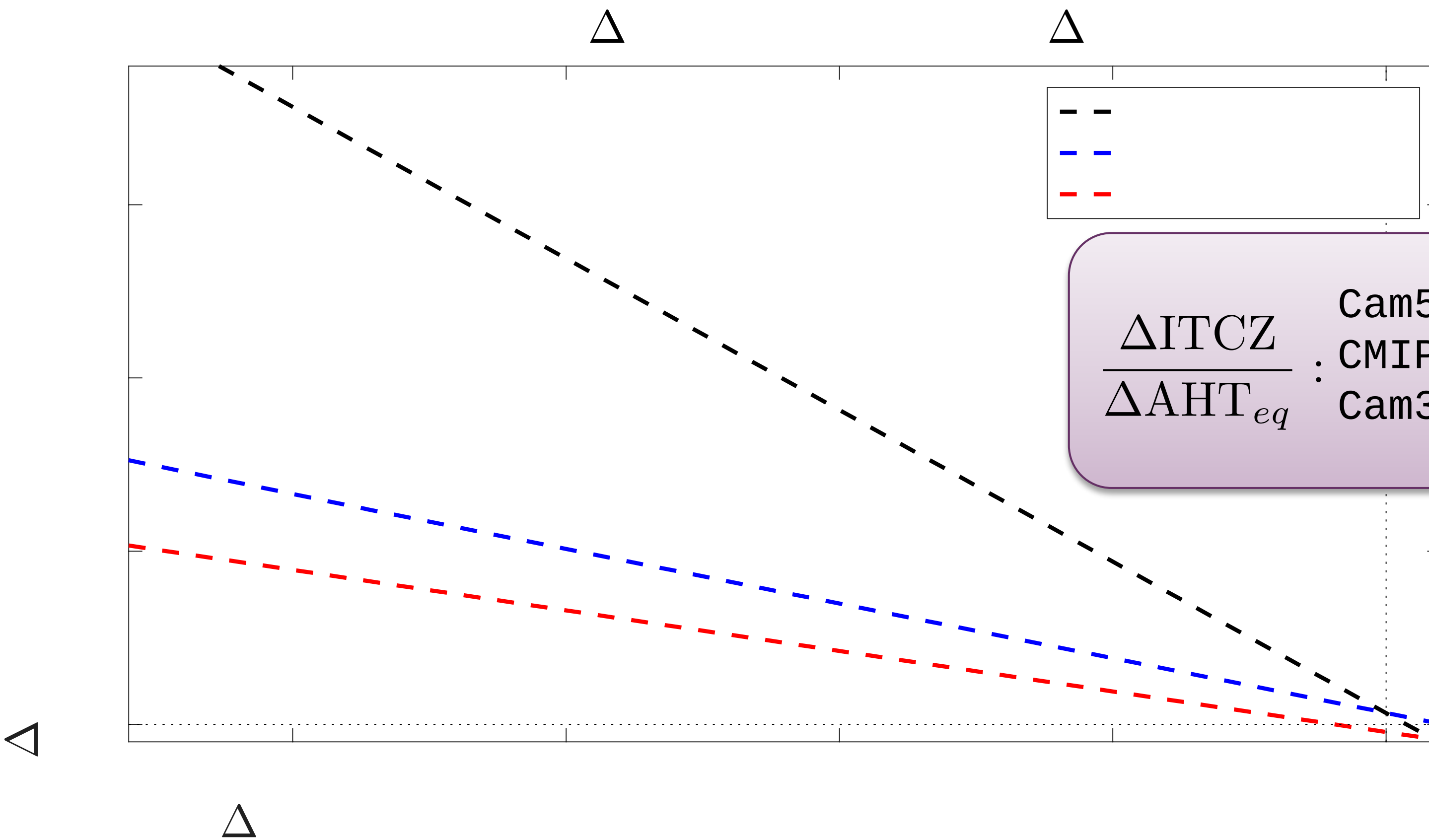
2. Before water threshold, increased clouds compensate for darker surface.
   When water threshold is reached, more trees -> less clouds (troposphere dries)

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?



$$\frac{\Delta \mathrm{ITCZ}}{\Delta \mathrm{AHT}_{eq}}:$$

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