“Nudging” to capture local atmospheric responses to vegetation change

…also Arctic shrub impacts on Arctic climate

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University of Utah

Collaborators:
Martyn Clark, Cory Wallace, Jennifer Baltzer, Sean Carey

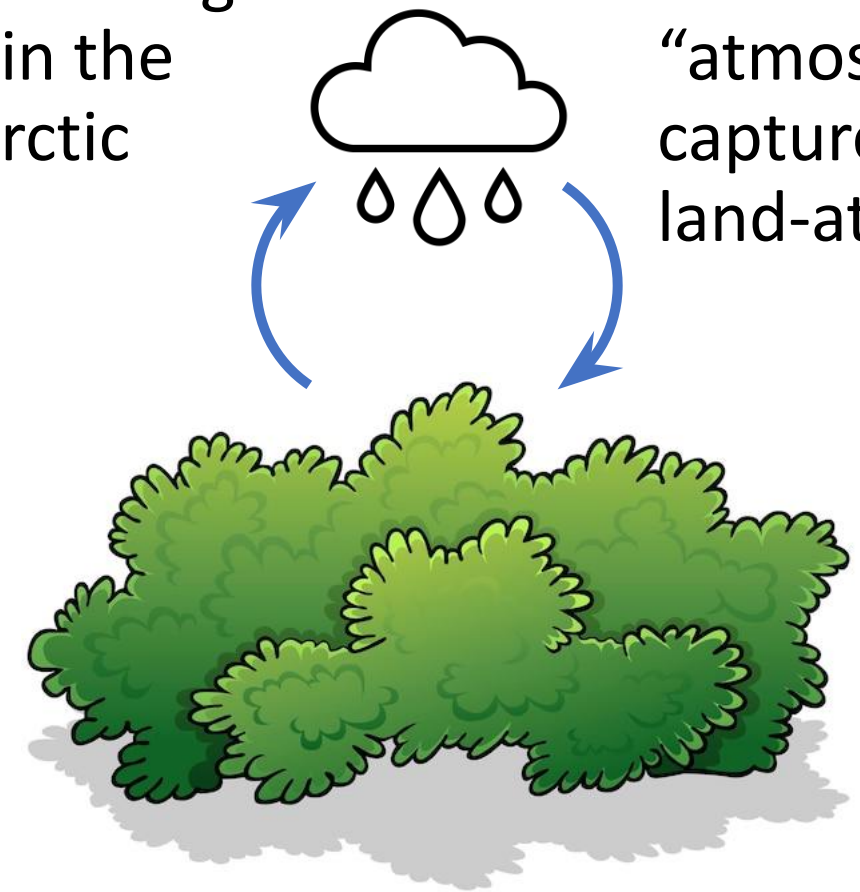
NSERC CRSNG

Goals:

- Determine how increasing woody vegetation in the Arctic influences Arctic hydroclimate

Not-so-secret 🤭🤫 Goals:

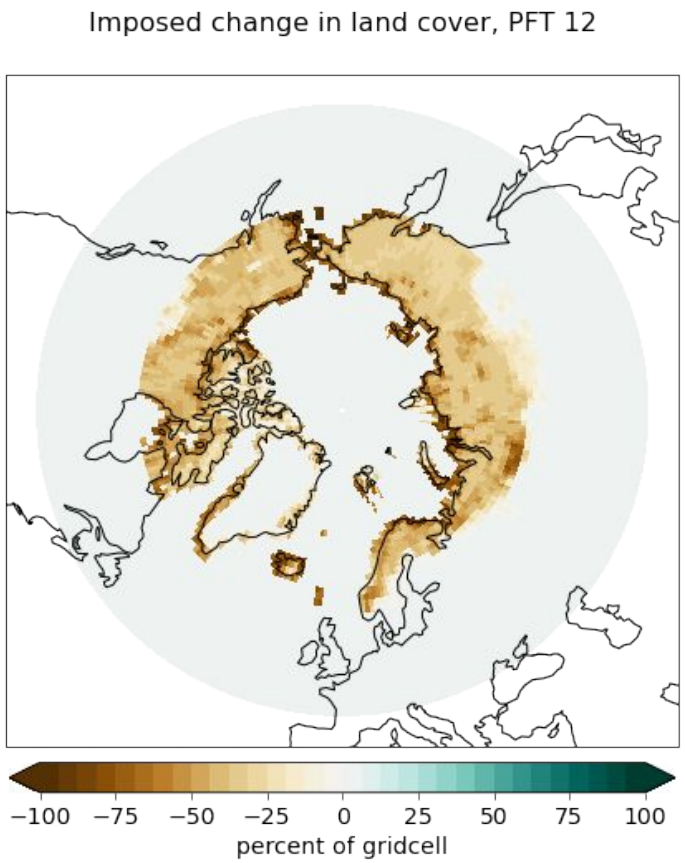
- Determine if we can use “atmospheric nudging” to capture local land-atmosphere coupling

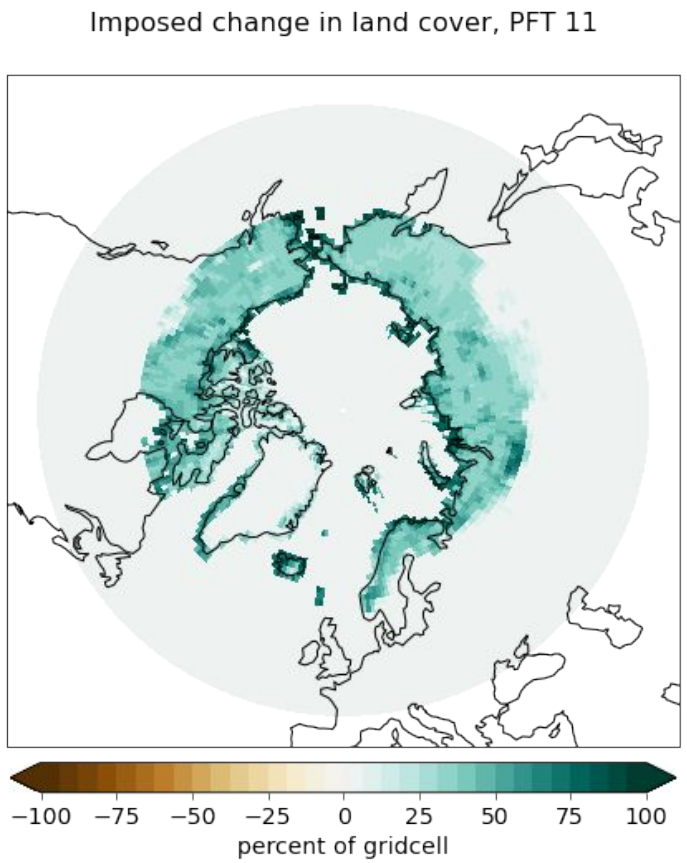


What we did:

- CLM5 and CLM5-CAM6 simulations
- Changed all grasses (NOT bare ground) to shrubs north of 60 N

Decrease in grass

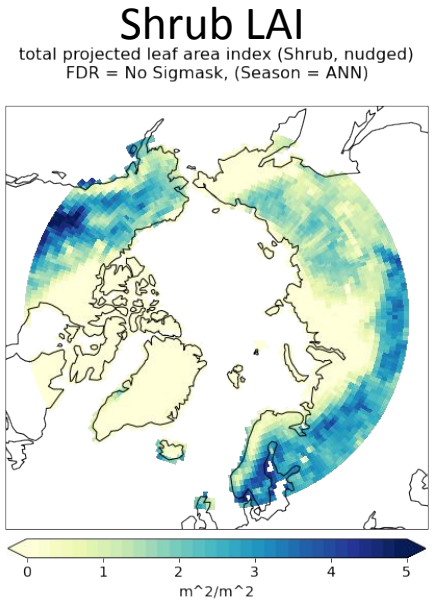




Increase in shrubs

Sanity check:
Are the shrubs dead?

Shrub LAI



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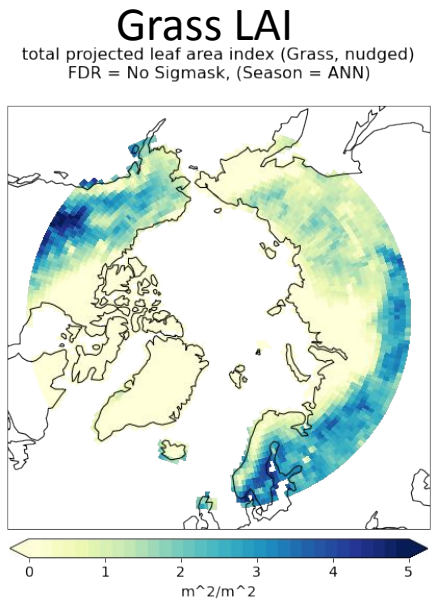
Grass LAI



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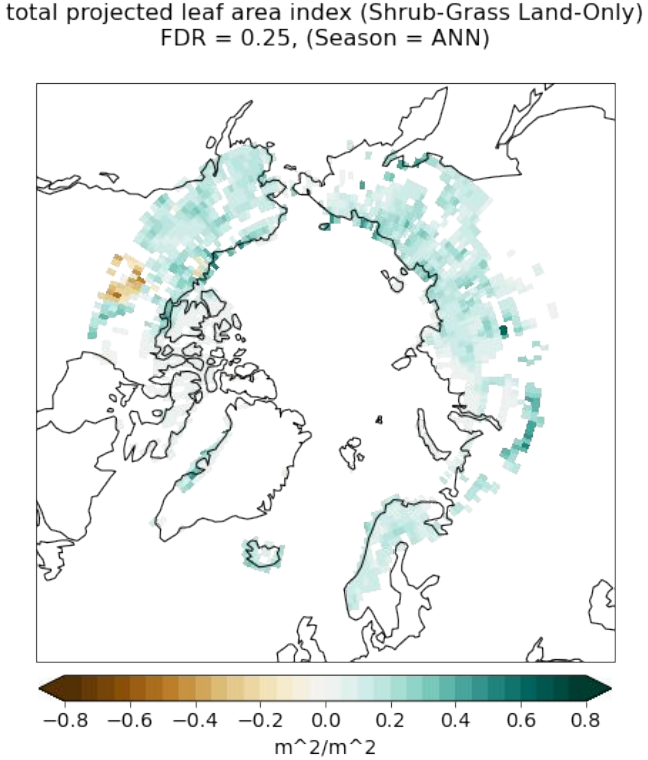
Shrub - Grass LAI



No. Good. Not everywhere, anyhow.

What *actually* we did:

- 3 pairs of simulations
  (grassy Arctic vs shrubby Arctic)

1. Fully coupled
   (CLM5-CAM6-SOM)

2. Land-only
   use the coupled control as the data atmosphere

3. Nudged
   Coupled, but push the large-scale circulation towards the control

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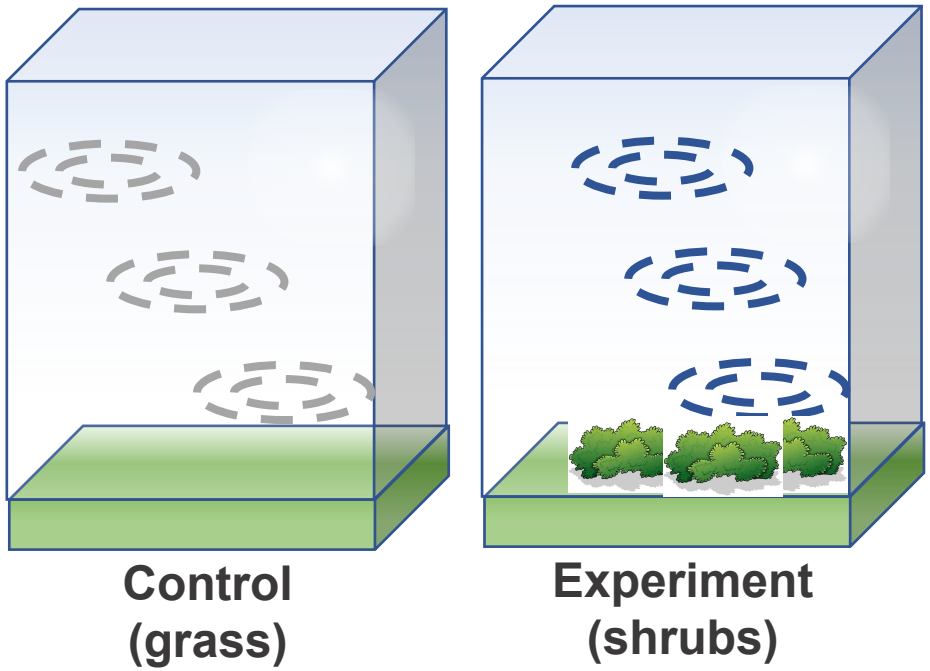

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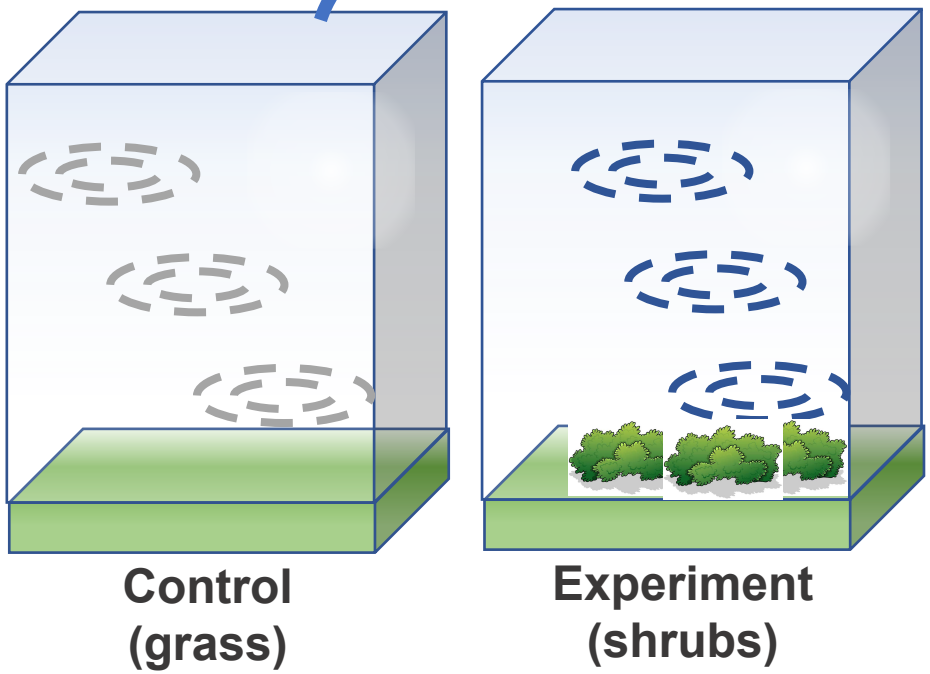

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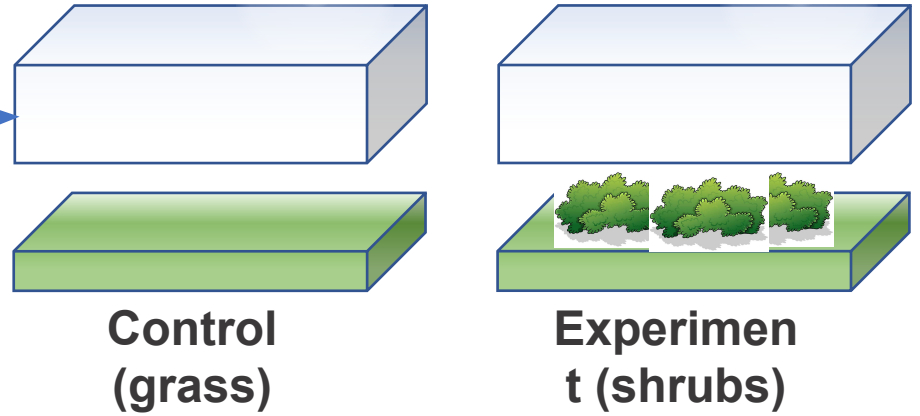

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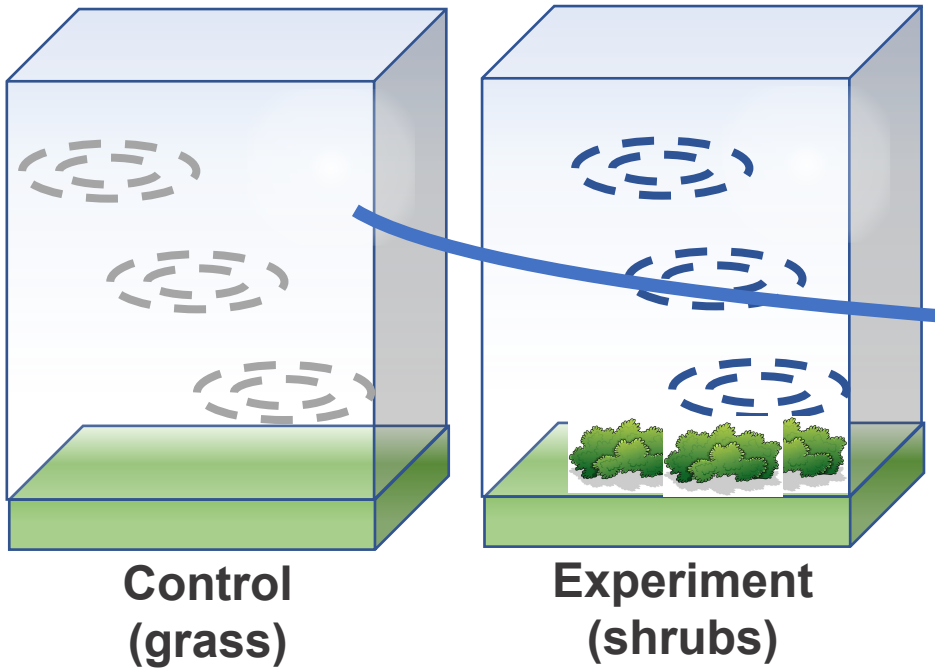

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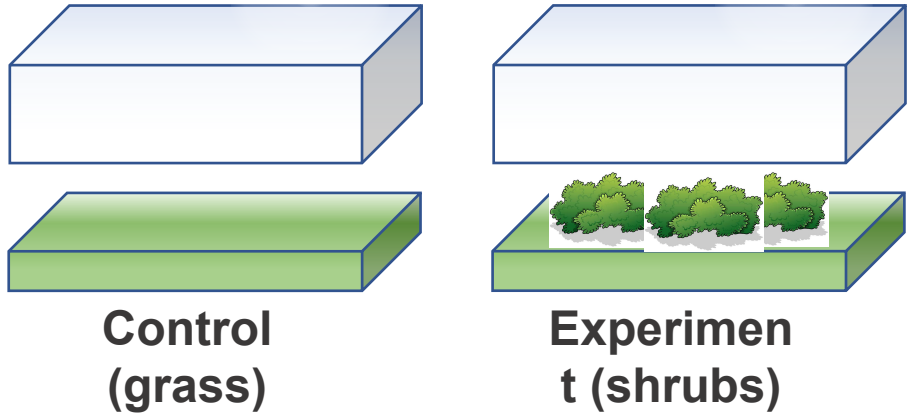

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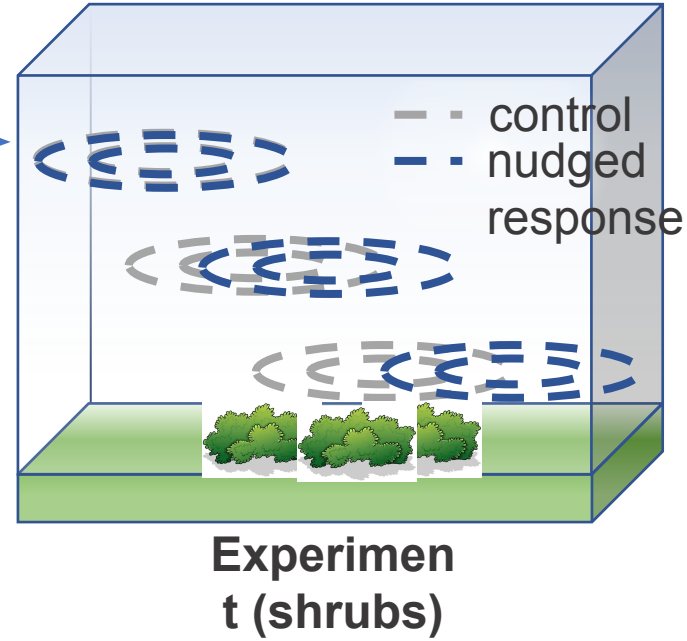

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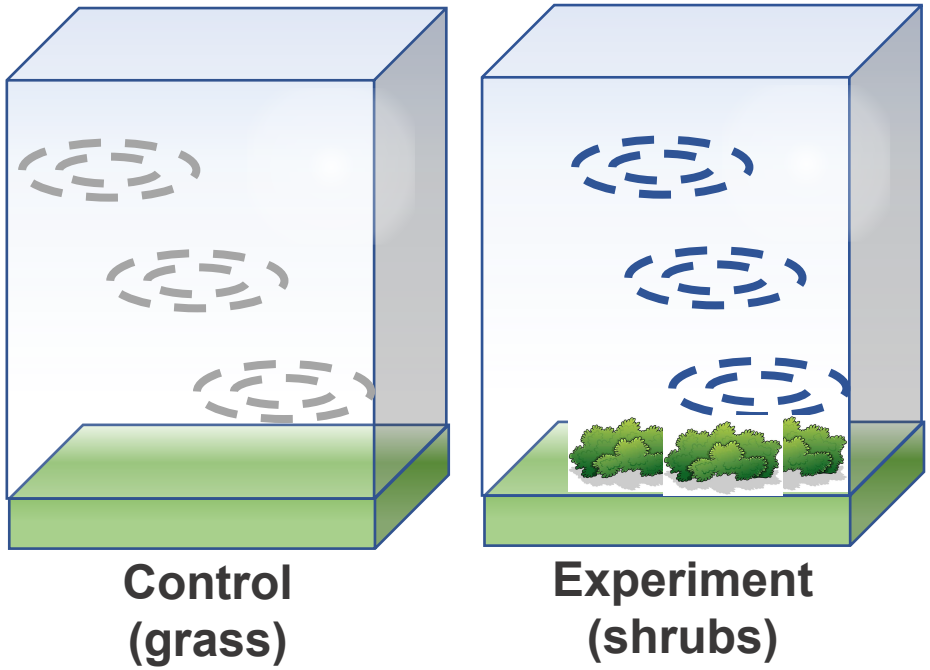

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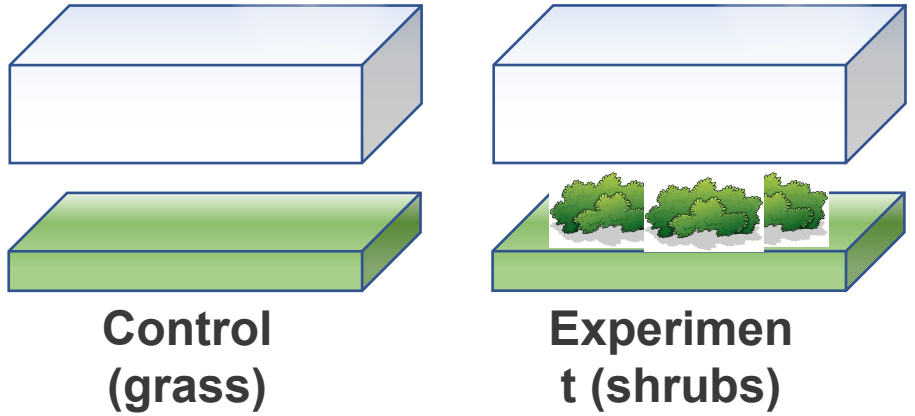

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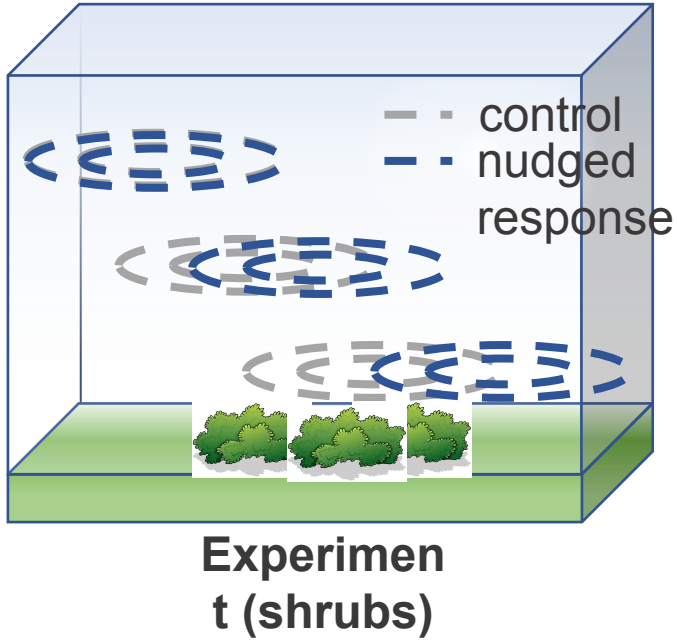
Coupled, but push the large-scale circulation towards the control

Nudged <u,v> winds above 700 hPa, every hour

- Why every hour?
- Why 700 hPa?
- I felt like it…



Shrubs lead to warming (more absorbed solar radiation)

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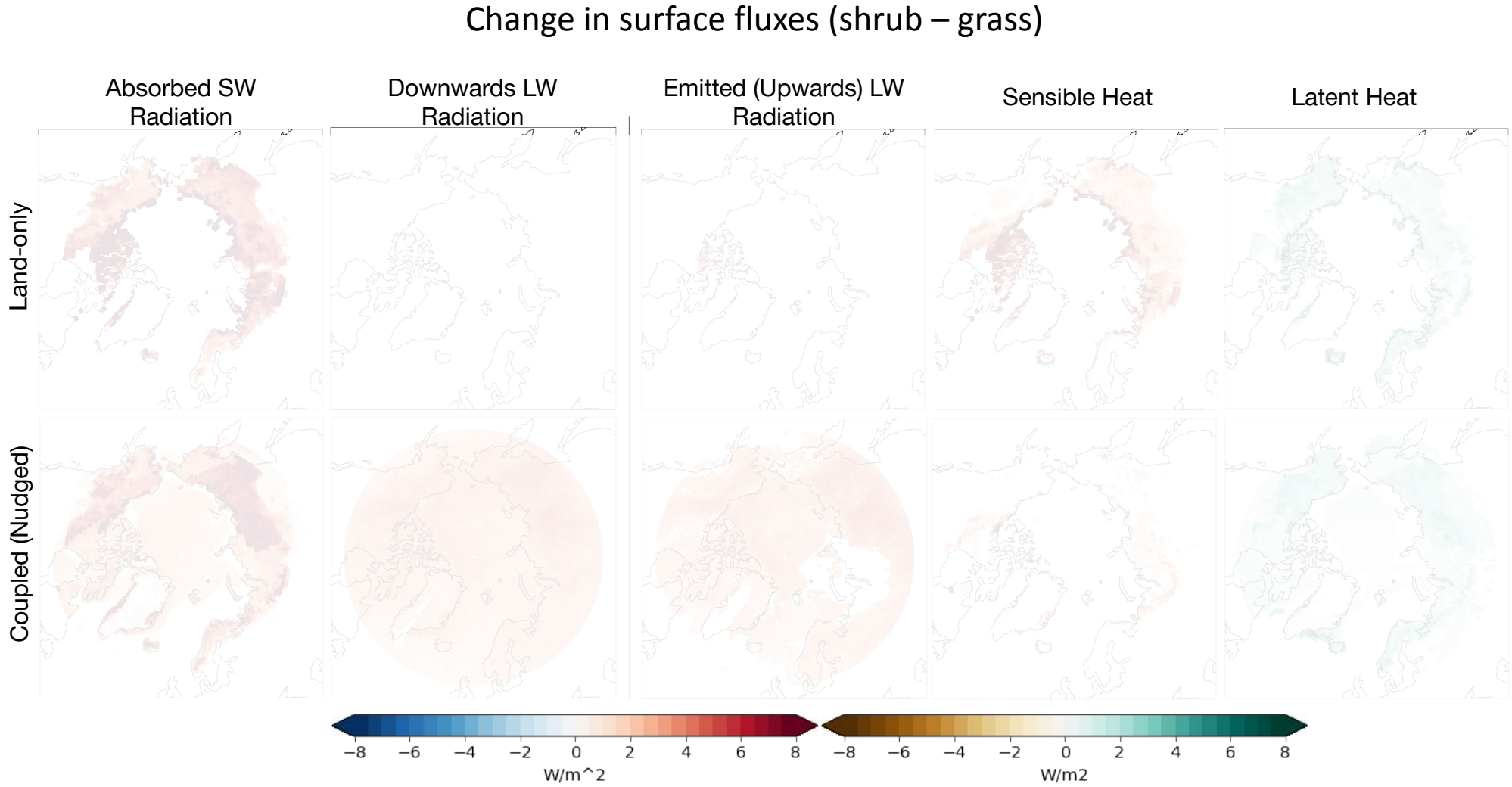
- Coupled simulations have some extra warming from a local longwave feedback (warmer atmosphere)



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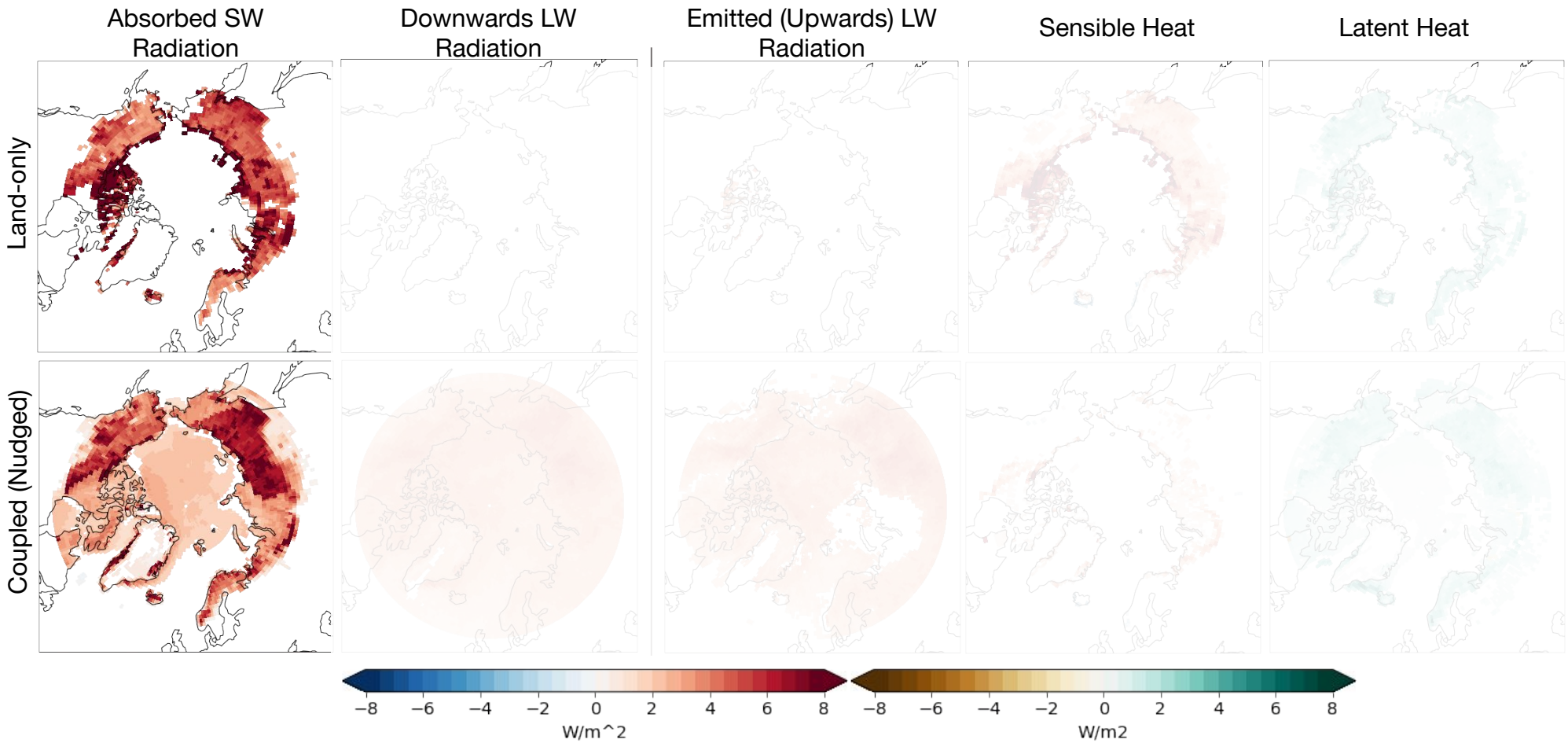

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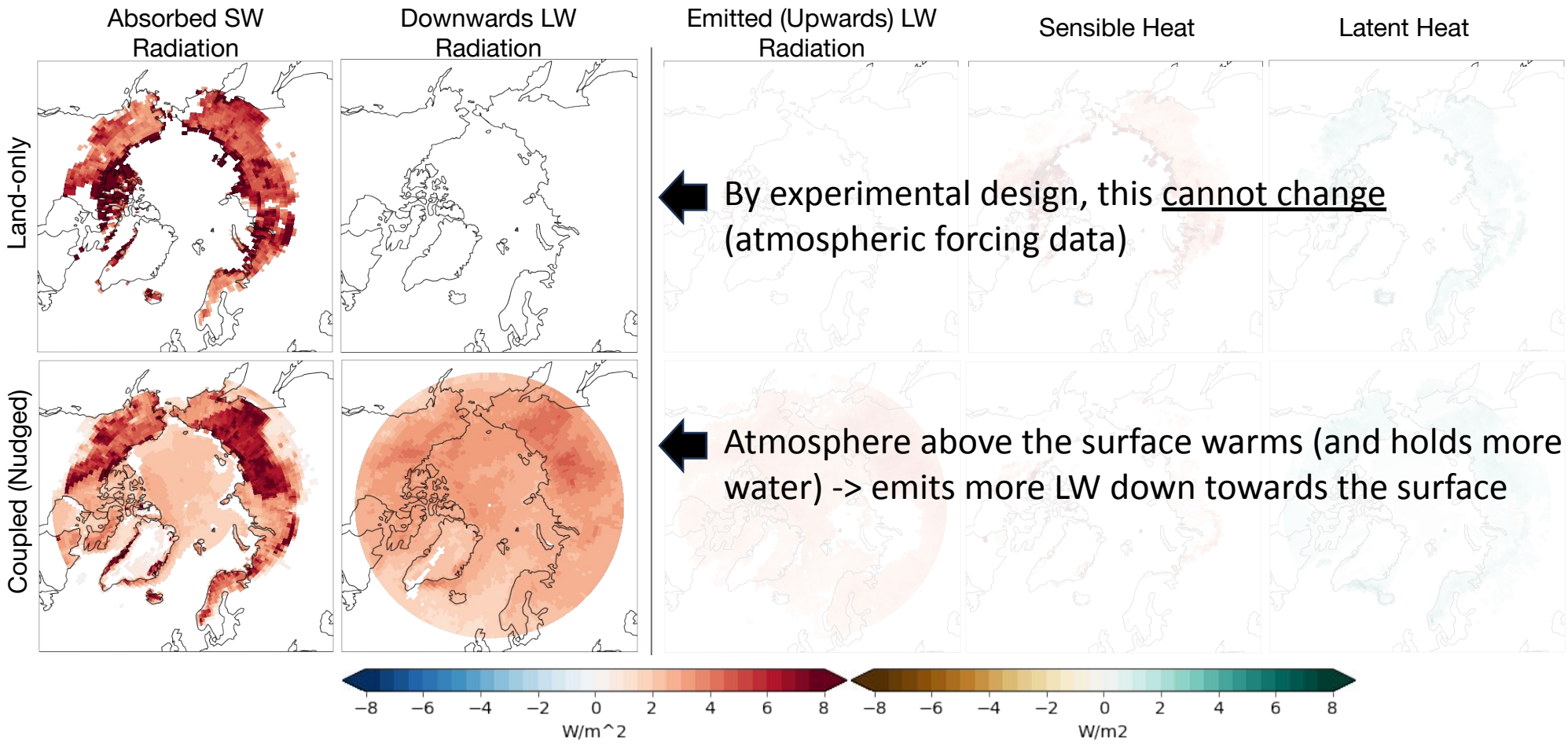

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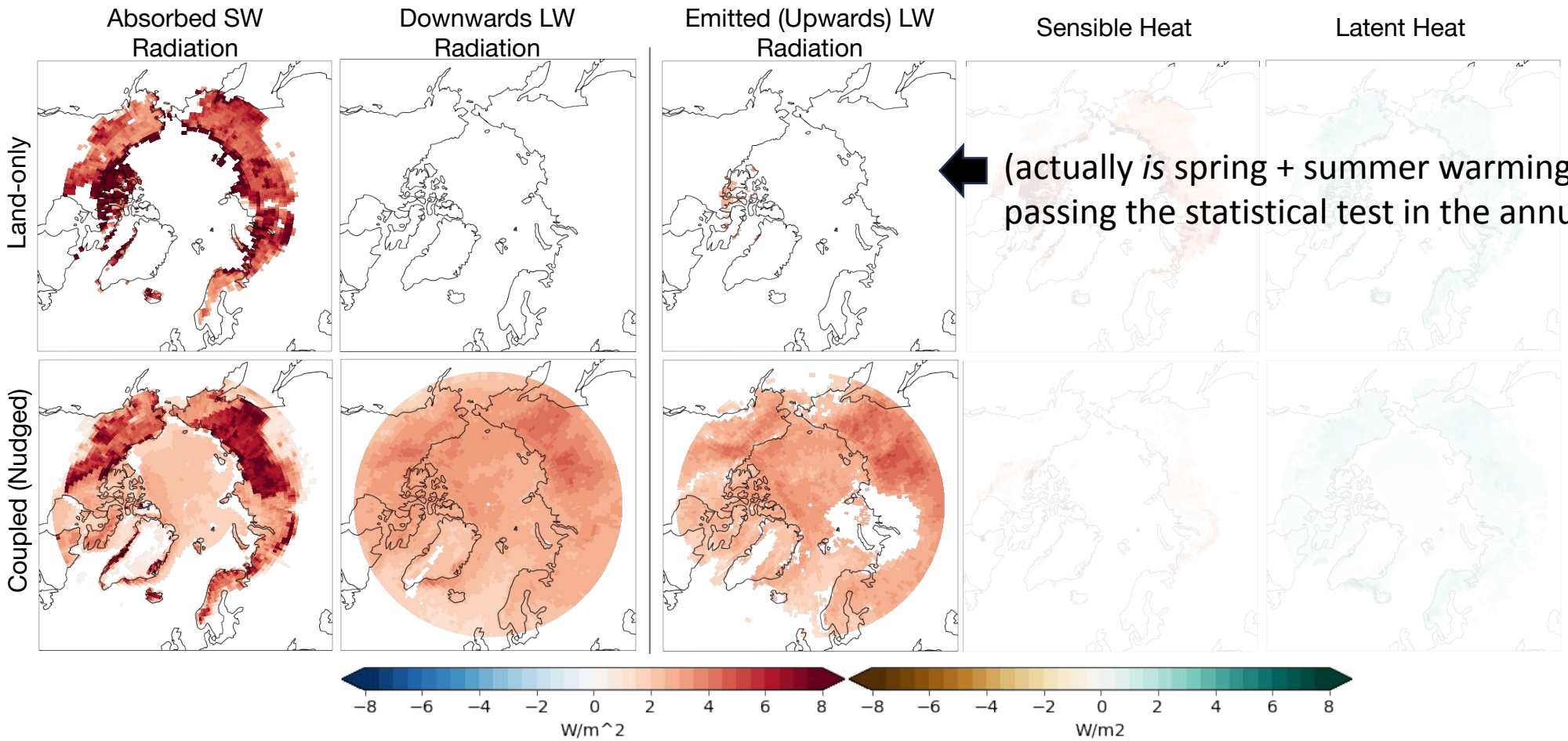

(actually *is* spring + summer warming, just isn't passing the statistical test in the annual mean)

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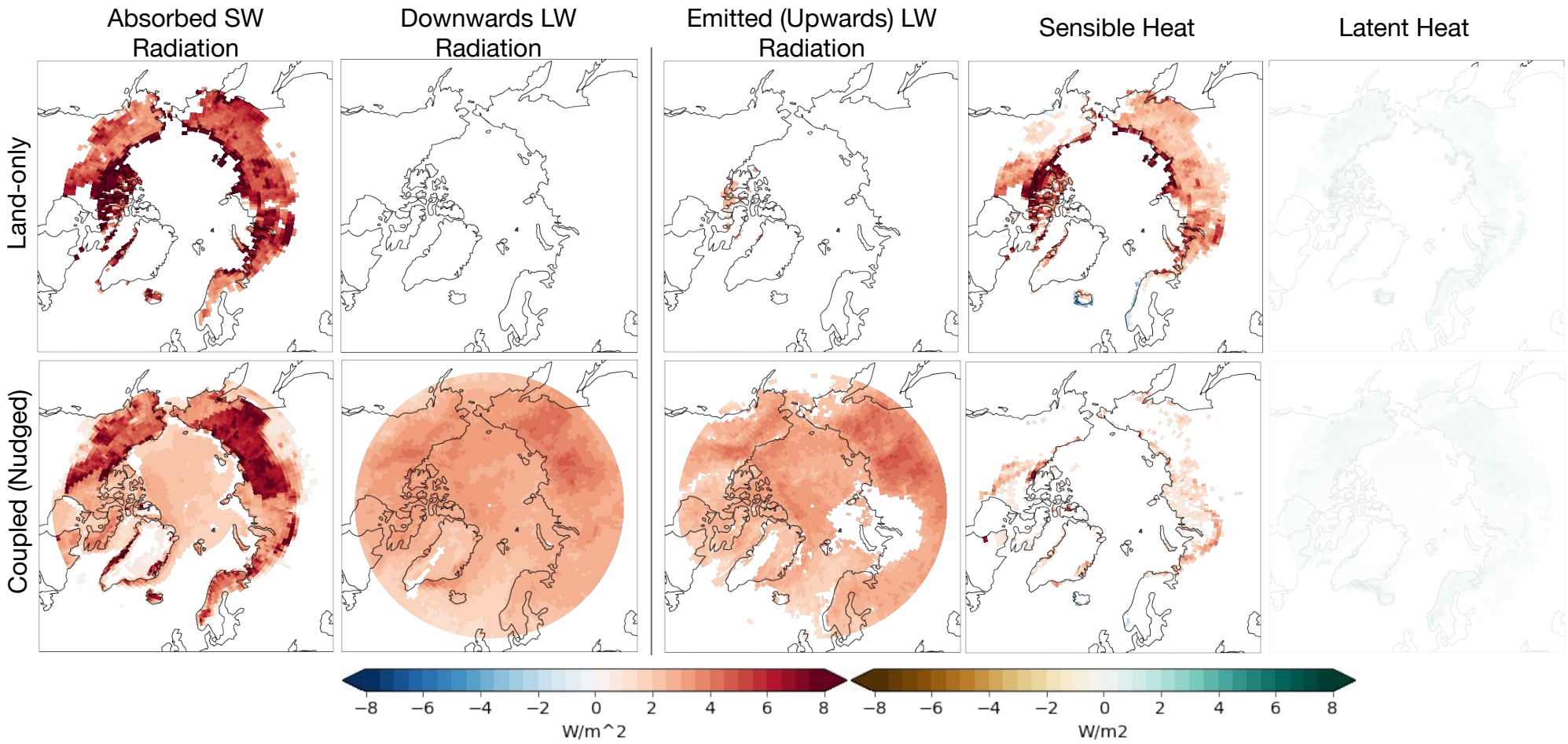

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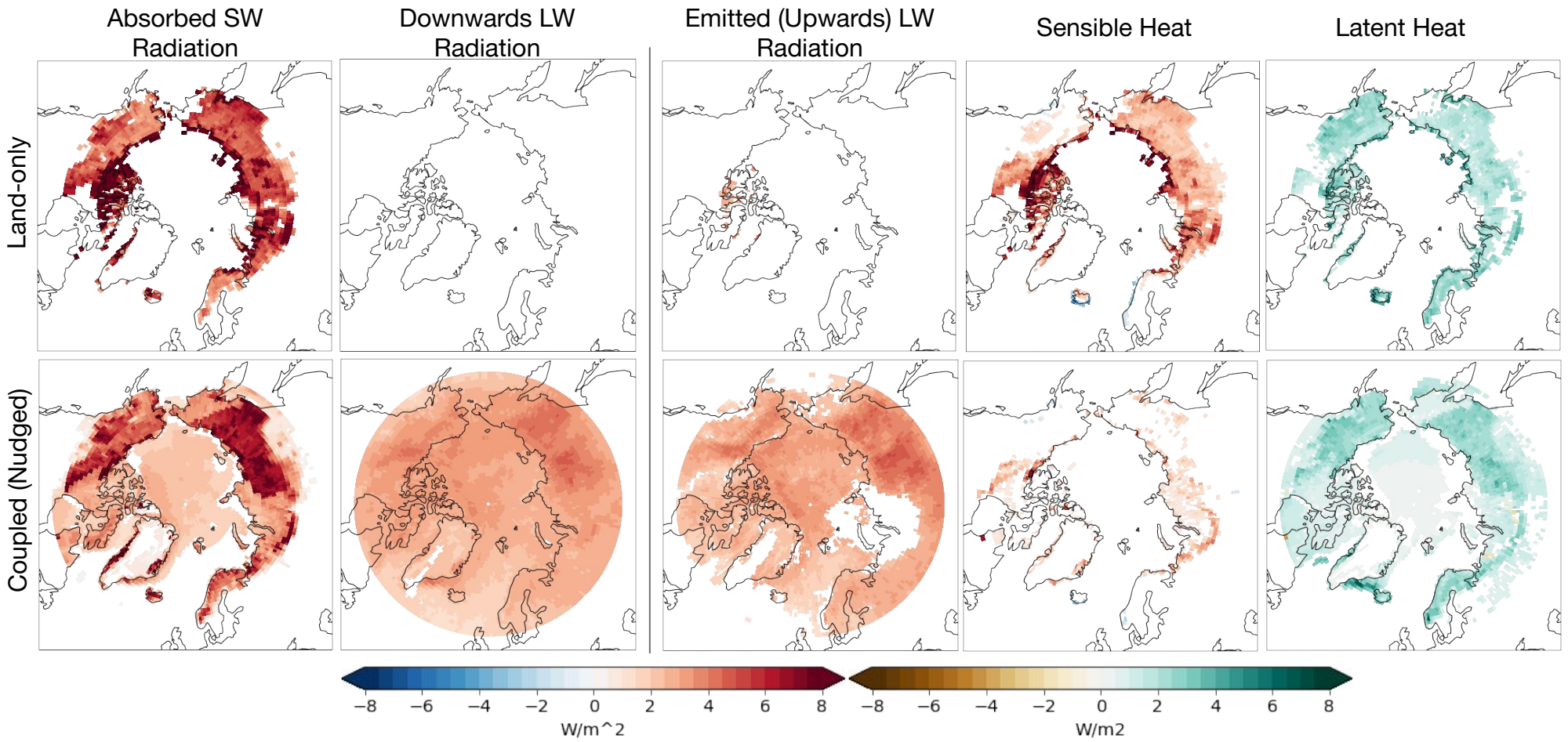
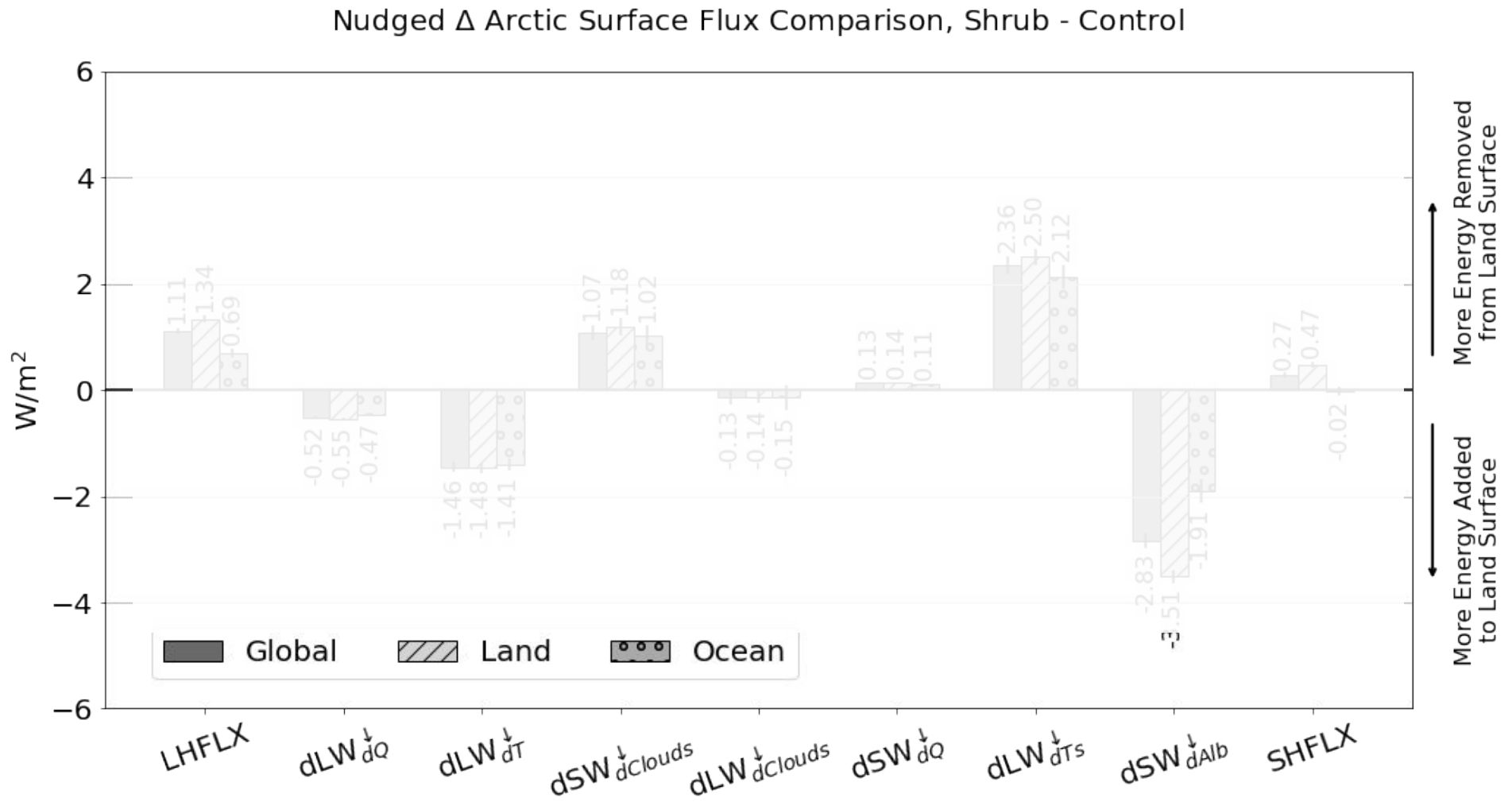


Increased shrubs lead to warming from:

- More SW absorption
- almost as much combined warming from combined increase in air temperatures and water vapor (dLW_{dT} and dLW_{dQ})
- Warming is damped by cooling from more evapotranspiration (LHFLX) and shortwave cloud changes



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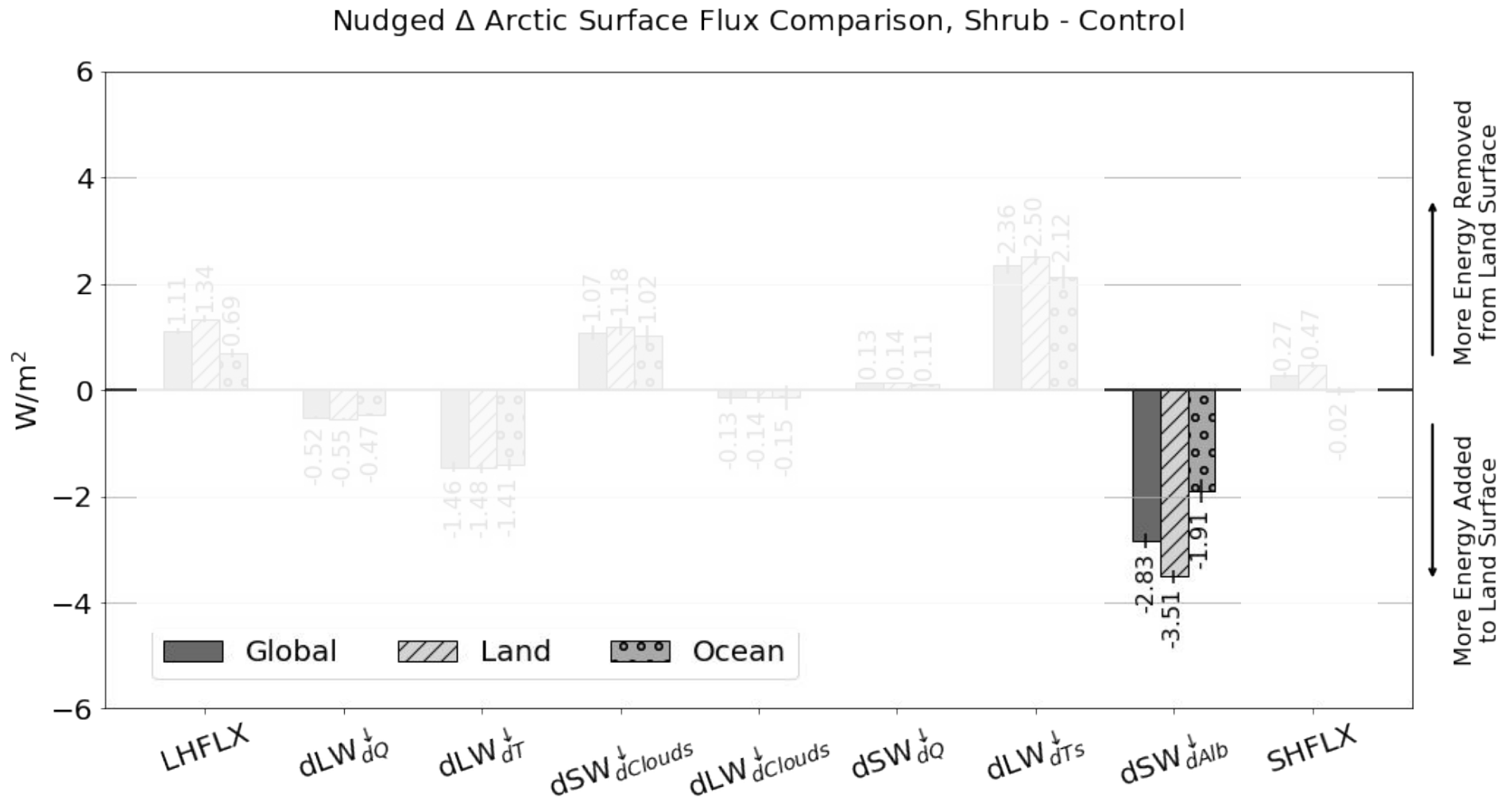

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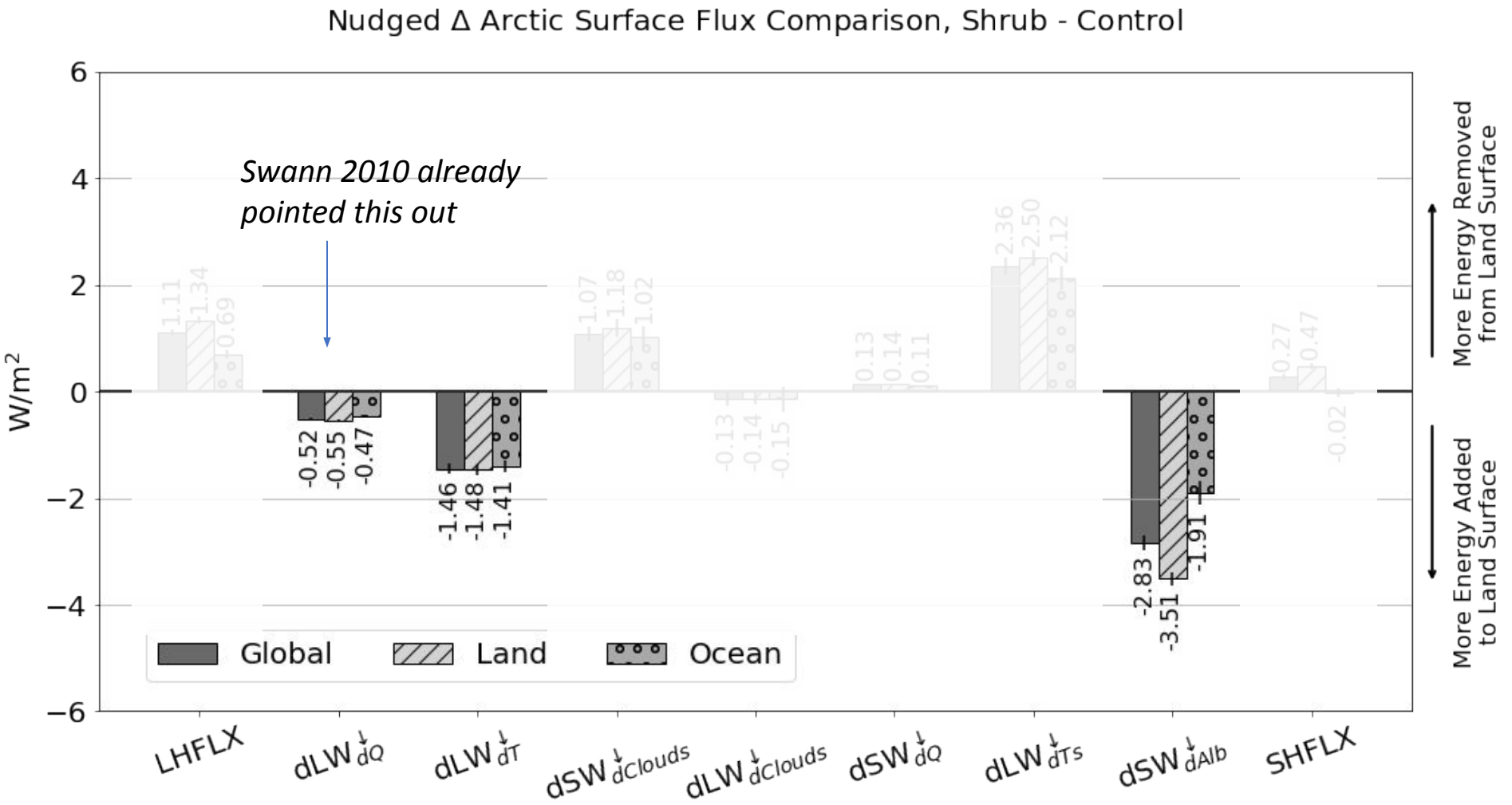

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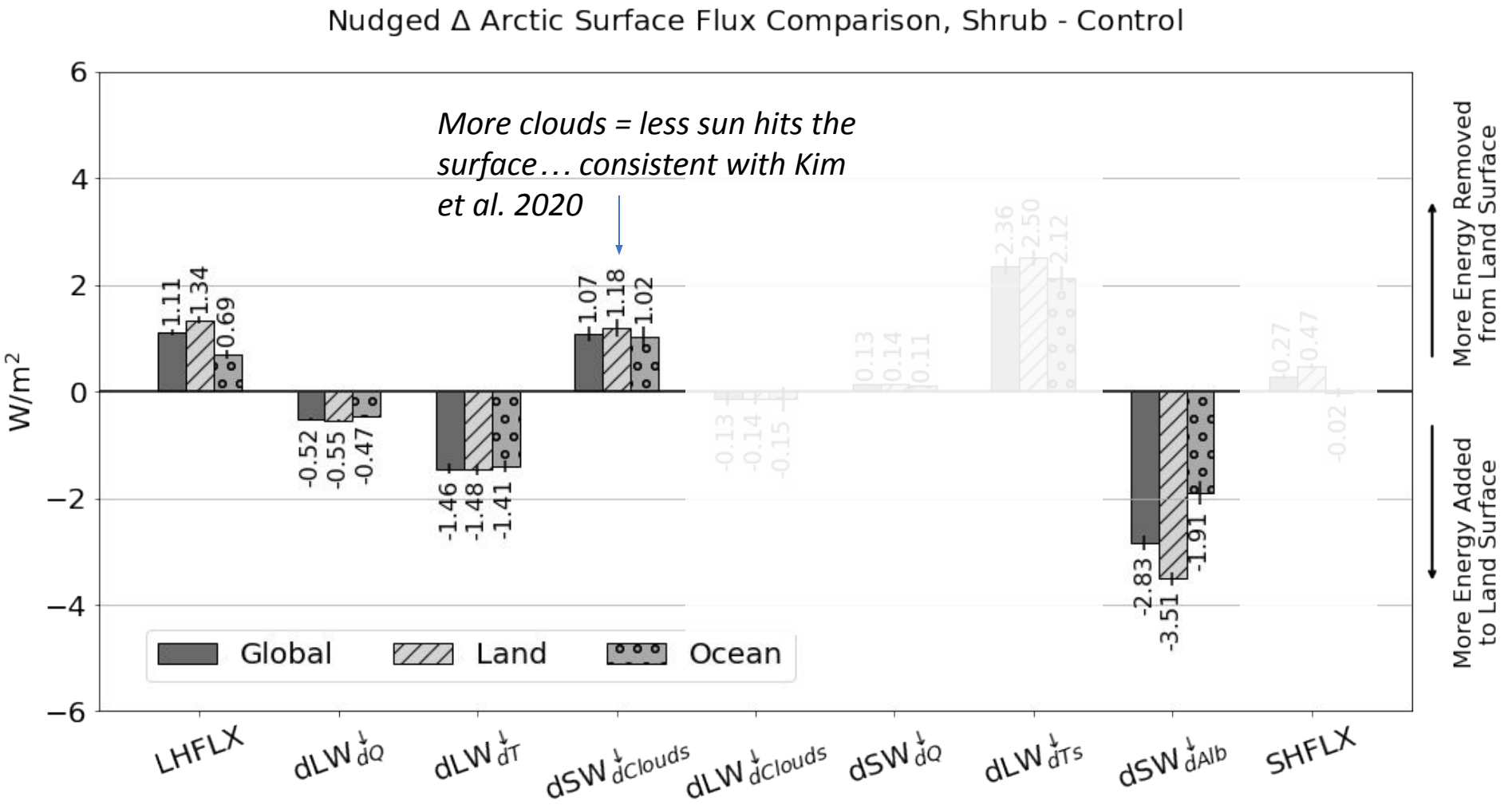

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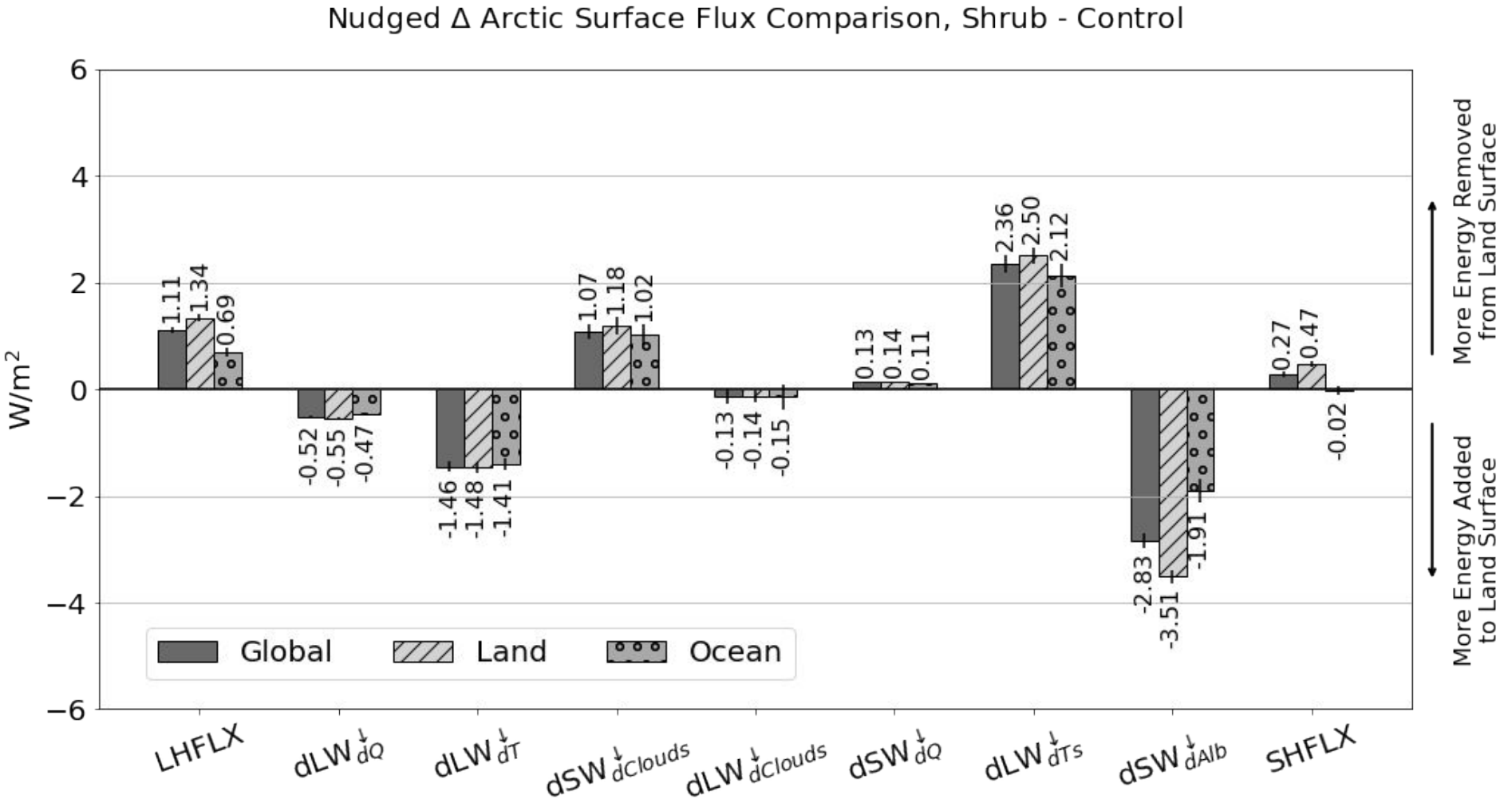

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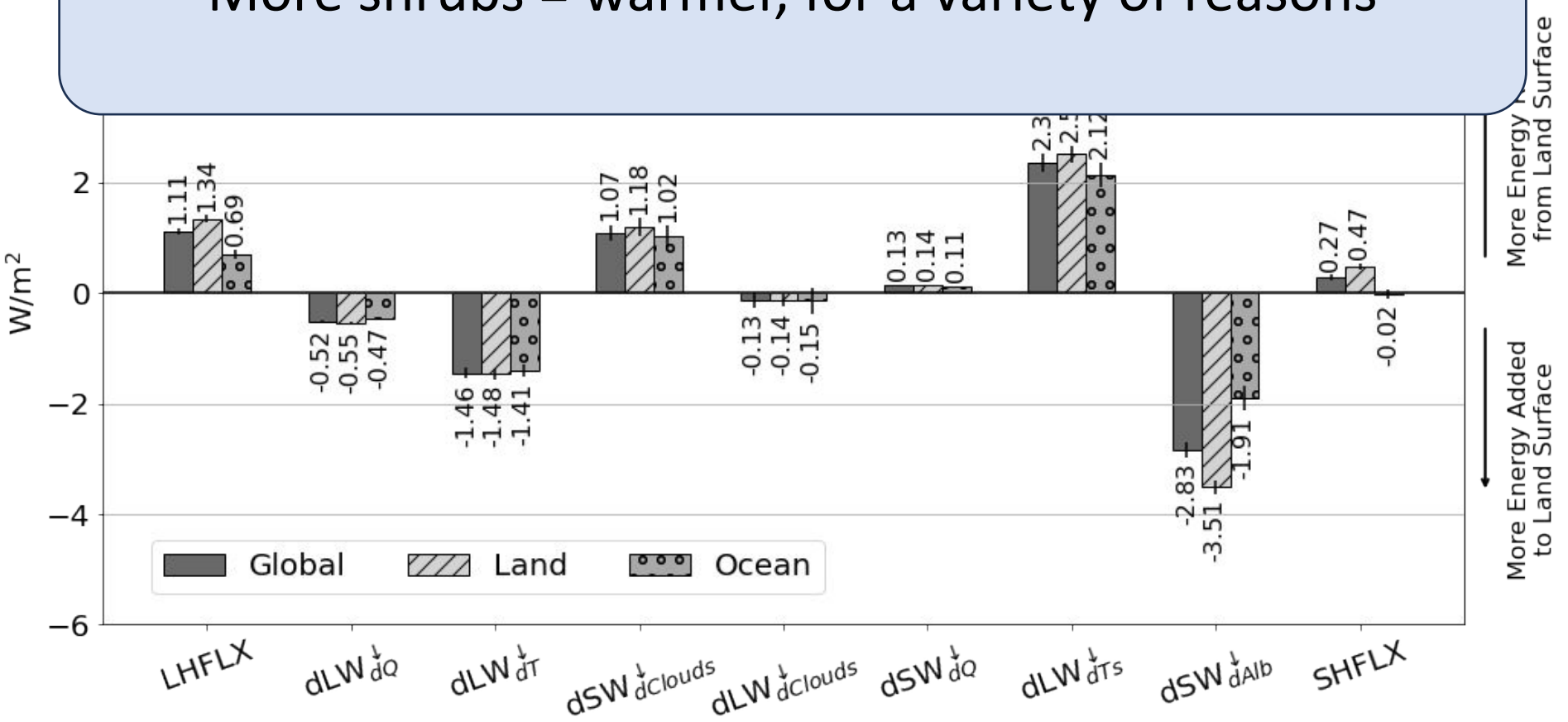
More shrubs = warmer, for a variety of reasons



I used this experiment as an excuse to try "nudging" the atmosphere

- 3 pairs of simulations, each with 1 shrub & 1 grass simulation
- Land-only (forced with coupler data from the coupled control)
- Fully-coupled
- Nudged:
  - Ever hour, I push the atmospheric circulation above 700 hPa towards the control state
  - Why every hour? Why 700 hPa? Why NOT?
  - But there is probably an optimal time step + height to do this for capturing the bulk of land-atmosphere coupling

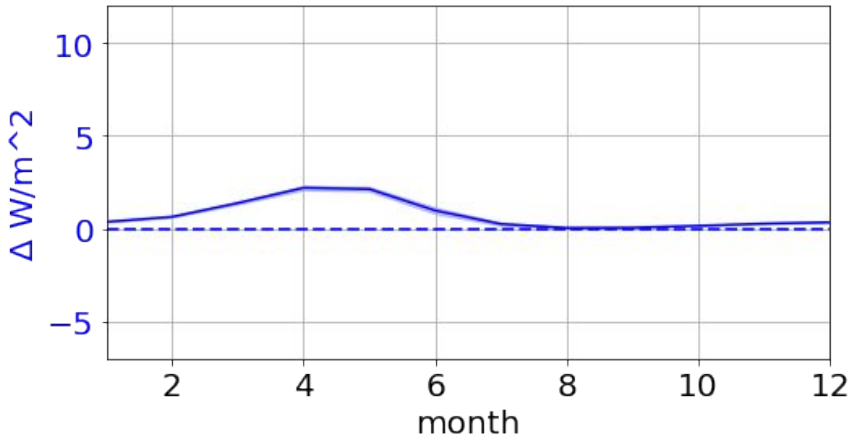
(function of surface temperature)

Nudging captures the best of both worlds:

- Magnitude of a coupled response
- Variability of a land-only response

Emitted Longwave Radiation
(Arctic ice-free land mean, Shrubs - Control)

Land-only



Land-only: Warms the surface in spring

(function of surface temperature)

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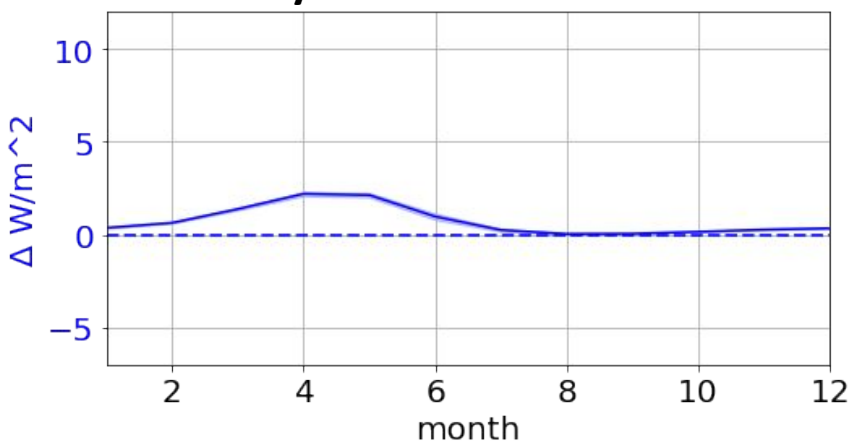

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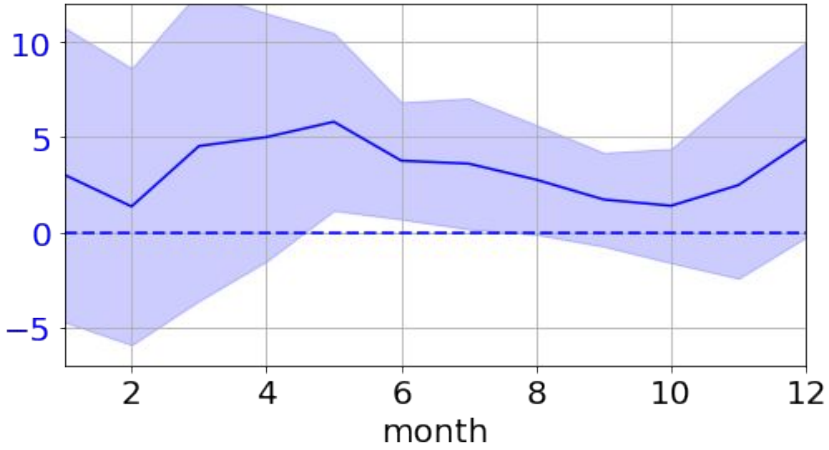
Fully-Coupled



Fully coupled: warms the surface year round (largest in spring); more warming than land-only. More interannual variability = harder to get the signal out of the noise.

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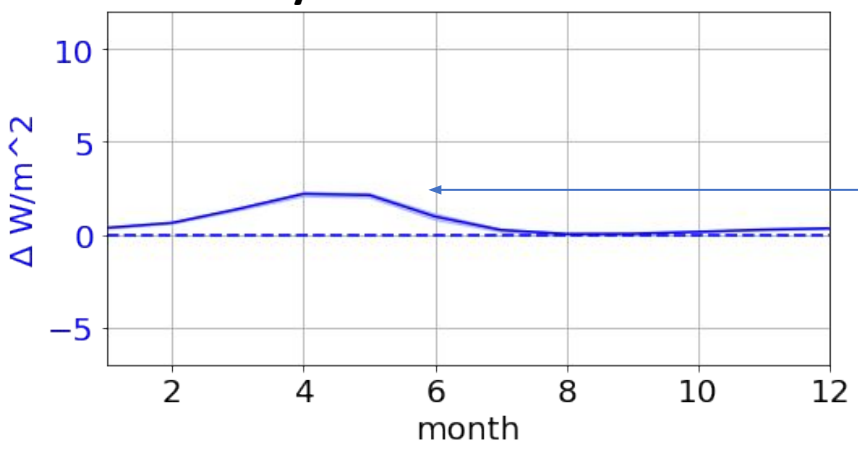
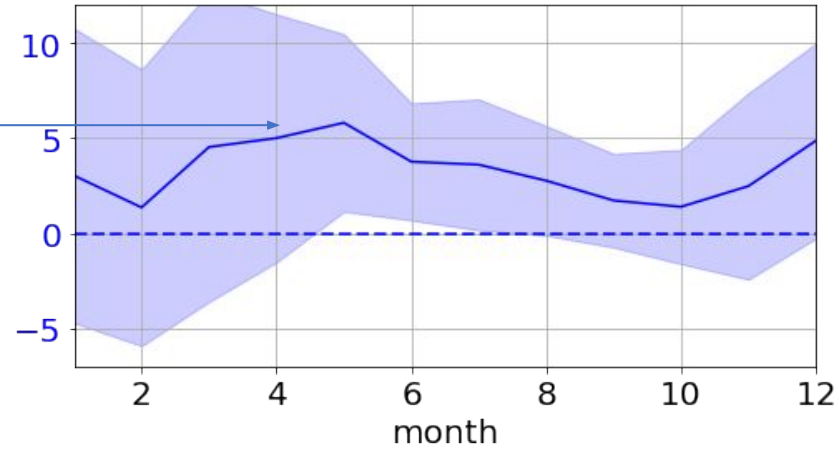


☹ 2x bigger change in coupled run

Fully-Coupled



☹ Larger variability in coupled run

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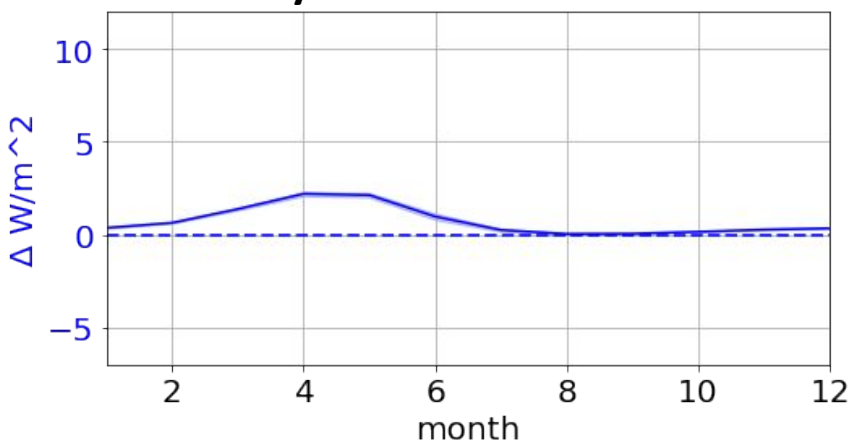

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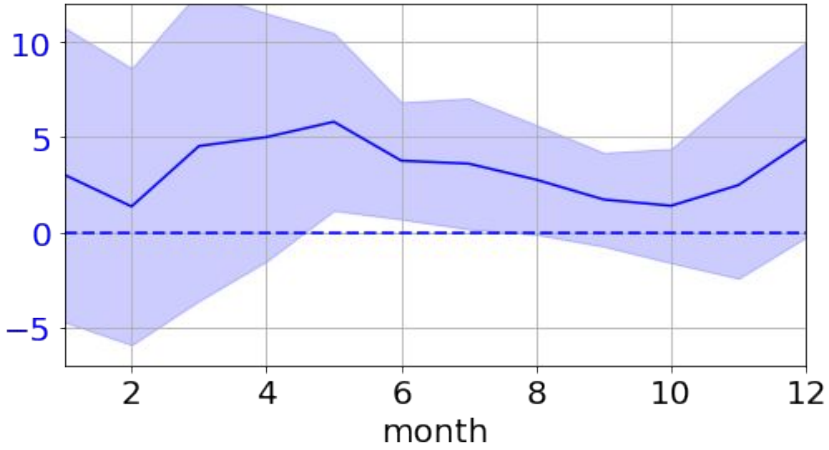

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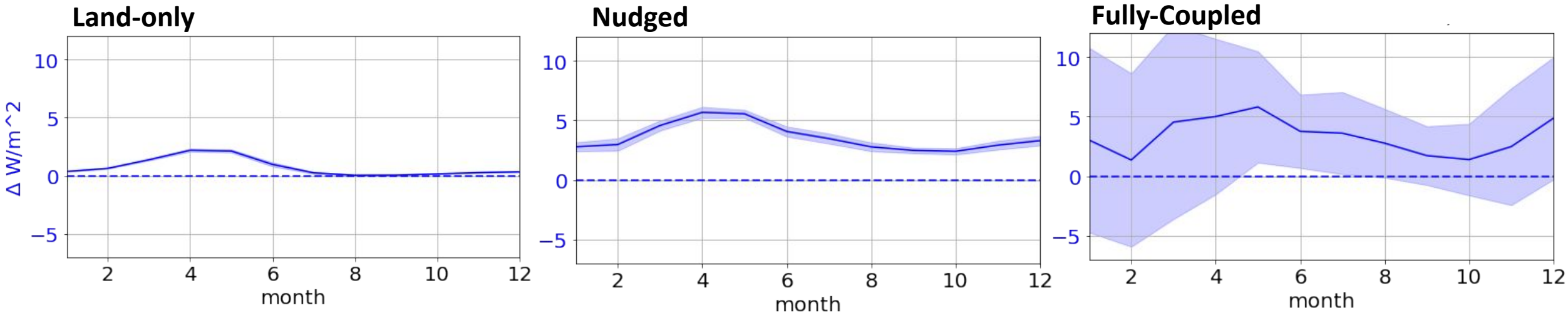

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Nudging seems promising!

Somewhat arbitrarily chose 700 hPa and every hour for nudging…

- As frequent as 30 min, maybe as long as 3 hours?
- "blend" the nudging vs a sharp gradient
- Choose a higher/lower level to start nudging at for different ecoregions?

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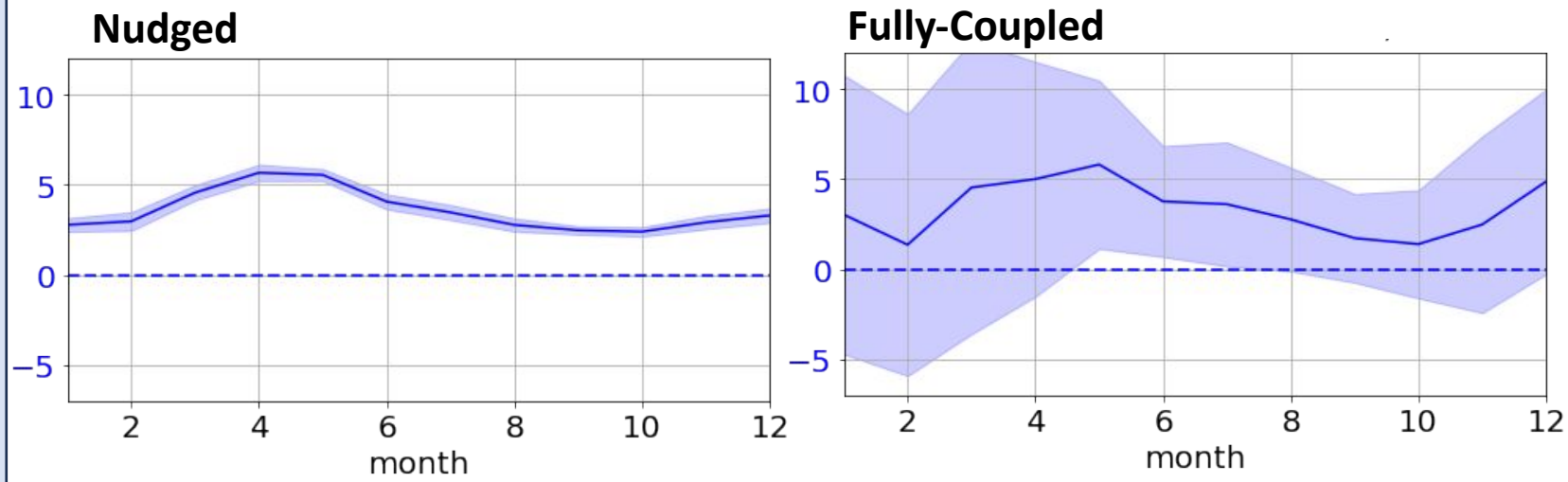

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Pros: ☺

- Magnitude of coupled response with variability of land-only run
- CAM folks built all the infrastructure for this… fairly* straight forward to implement

* okay, it took me several weeks to figure out how to make it work, but I was making a lot of mistakes along the way

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- **SLOW**: RIDICULOUS amount of input/output going on
  - Every hour, CESM has to go grab the full 3D output of a previous CAM run
- **Data-intensive**: Storing the high frequency atmospheric data to nudge *towards* takes up … almost my entire scratch space. Fun trying to run a simulation with no scratch space. Not ideal.
- Slower + more expensive than a free-running CAM simulation. Not ideal.
- **Stable?** Should formally check if it is actually technically numerically stable…
  - "Spectral ringing" & "Courant–Friedrichs–Lewy (CFL) conditions"

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1. Global runs where you don’t want to worry about teleconnections/remote impacts, but do want to capture some local atmospheric feedbacks
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    - You could just use a regional model, or MPAS – but if you want to compare to other CESM runs, this could make sense. Here, I nudged above 700 hPa, but you can also nudge the full column outside of a lat x lon box.

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2. Regional studies (like the Arctic one), where you sort of bully CAM into acting more like a regional model

    - You could just use a regional model, or MPAS – but if you want to compare to other CESM runs, this could make sense. Here, I nudged above 700 hPa, but you can also nudge the full column outside of a lat x lon box.

3. As a diagnostic for regions that are <u>likely to trigger</u> teleconnections

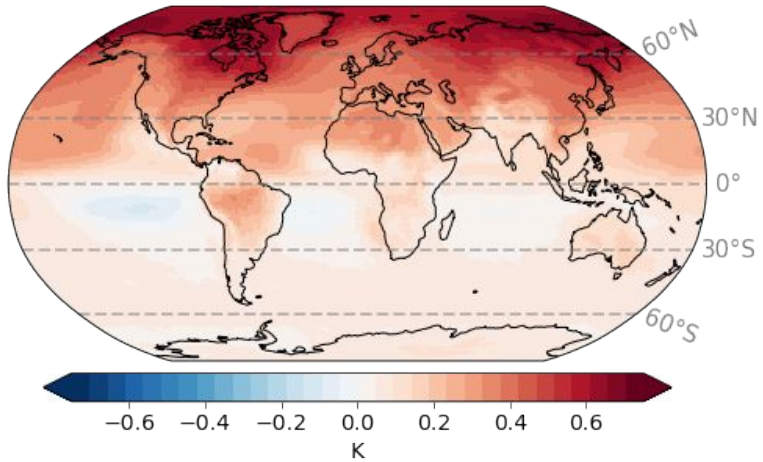
    - The local response doesn't know the upper atmosphere is going to be nudged. If the nudged atmospheric response can't "get rid" of a signal, you'd expect a change in circulation to occur.

Summary:

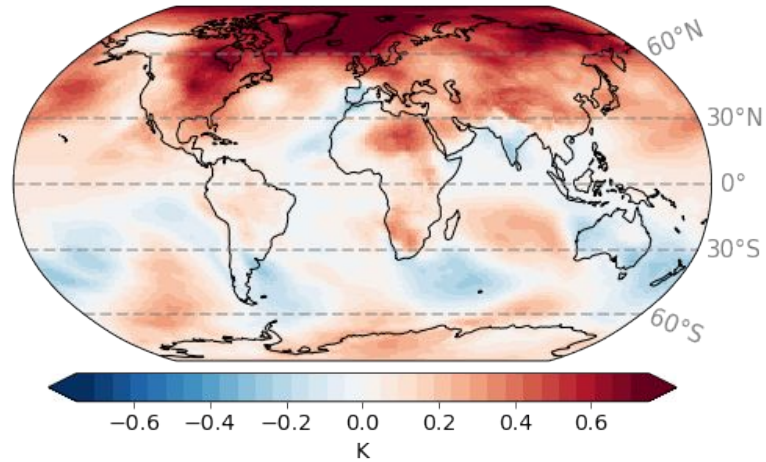
- Nudging the large-scale atmosphere circulation towards the control state captured the:
  - magnitude of response (in terms of surface energy fluxes) you'd get in a coupled simulation
  - Variability of response you'd get in a land-only simulation
- Feedbacks (largely a temperature longwave feedback, partly a water vapor and cloud feedback) roughly double the impact of Arctic shrubs on (spring) temperatures.

(fin)NI!

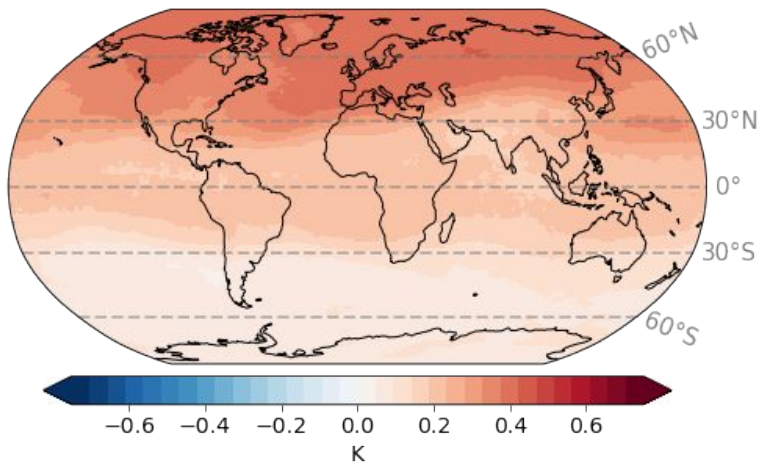
Nudged ΔT (at 900hPa)
(Experiment - Control)



Fully Coupled ΔT (at 900hPa)
(Experiment - Control)



Nudged ΔT (at 400hPa)
(Experiment - Control)



Fully Coupled ΔT (at 400hPa)
(Experiment - Control)