The importance of atmospheric feedbacks when considering land surface changes

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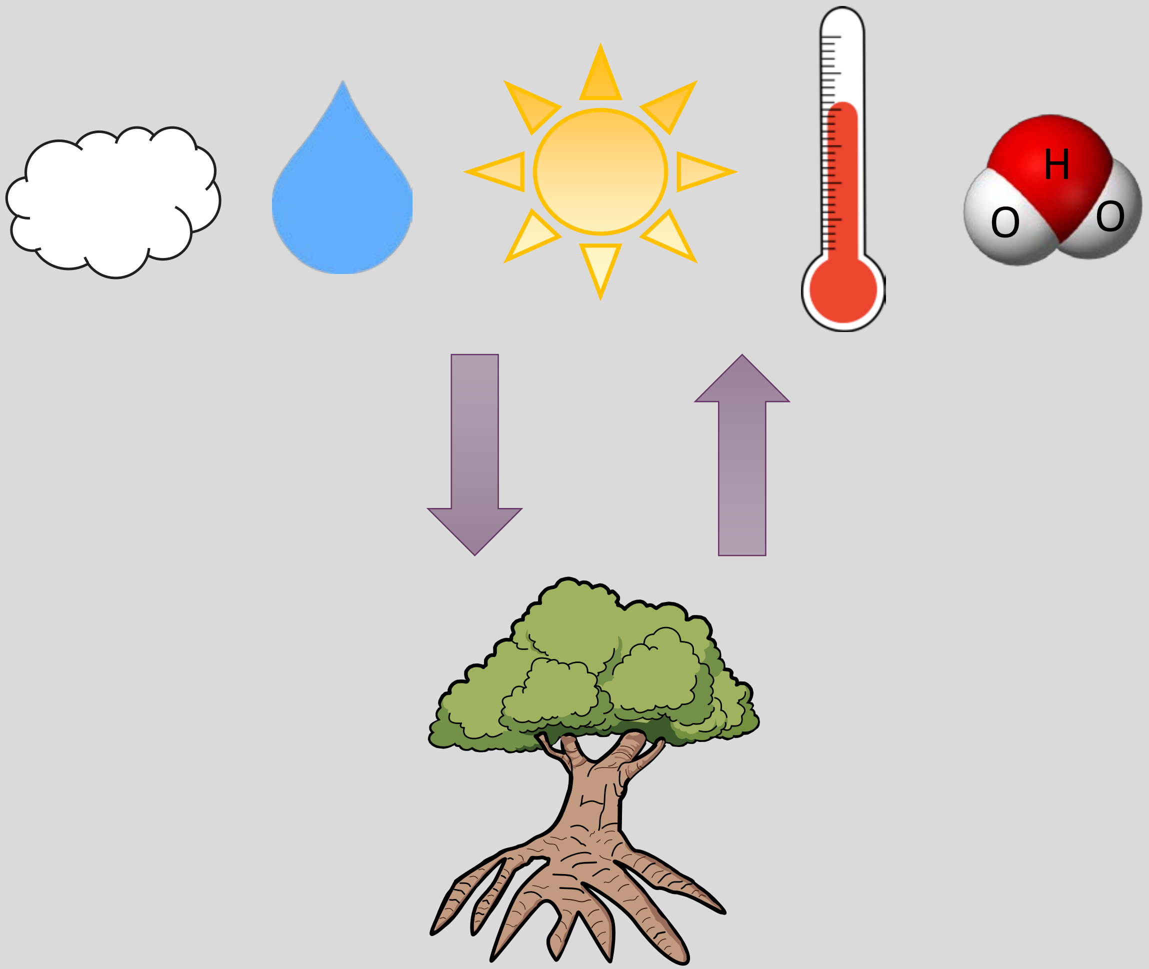
NSERC CRSNG

The importance of atmospheric feedbacks when considering land surface changes

Surface properties don't have the same impact on the atmosphere everywhere (location matters)

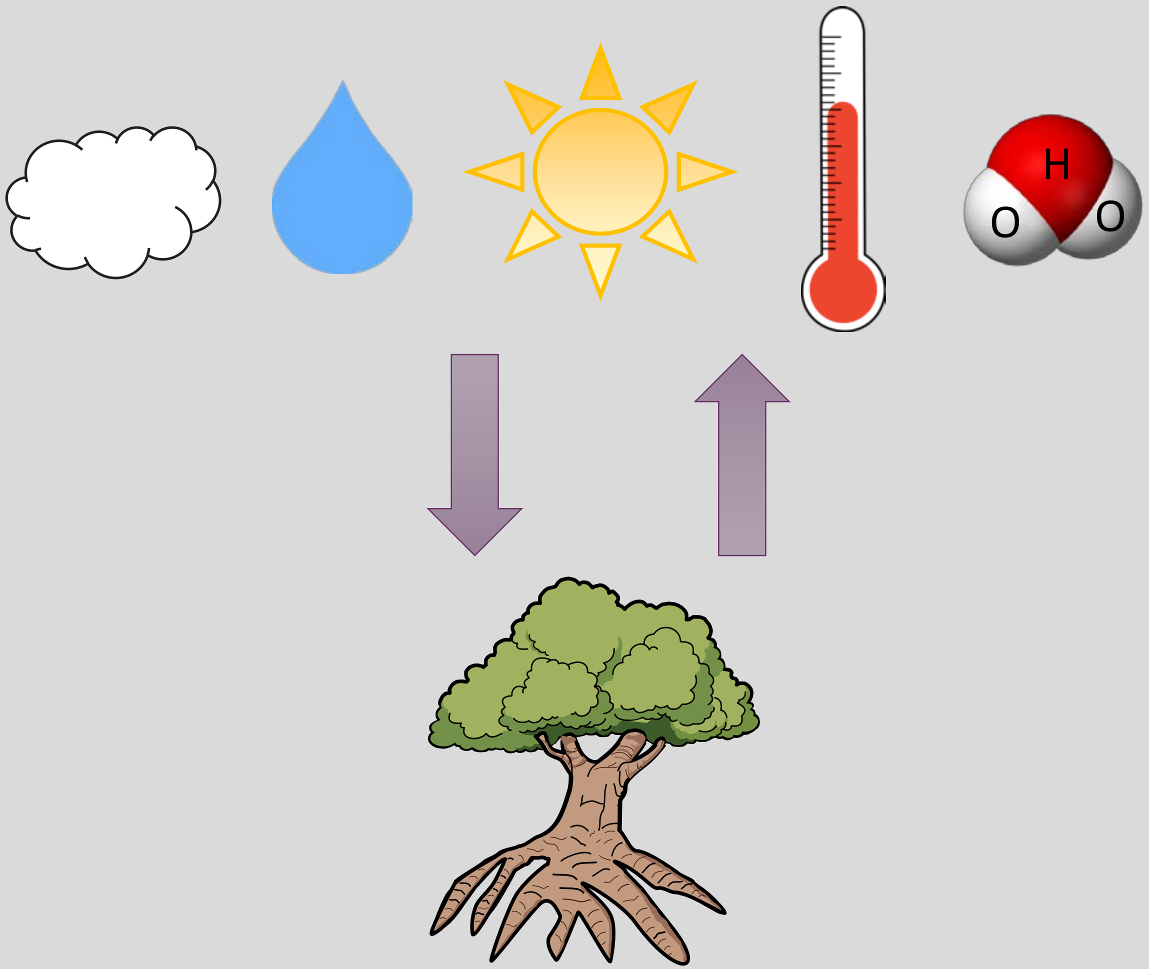
Total climate signal is a combination of **direct** surface responses and atmospheric **feedbacks**

The land & atmosphere interact through the surface energy budget



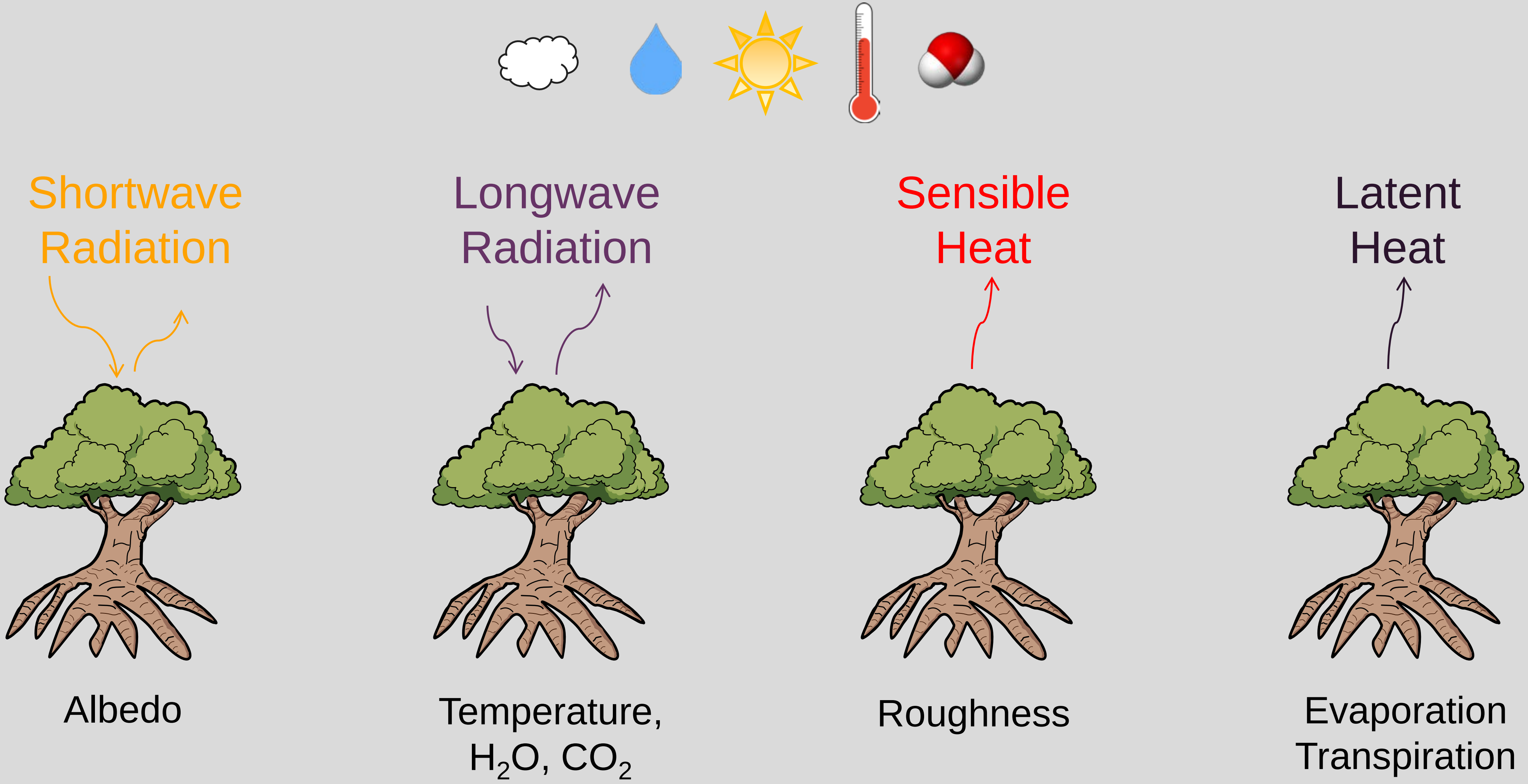
The land & atmosphere interact through the surface energy budget

Climate influences vegetation

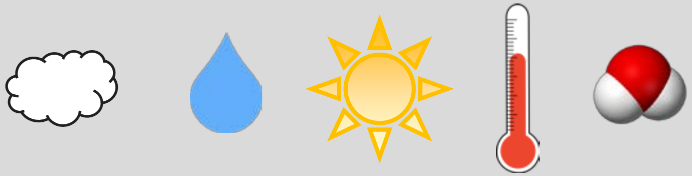


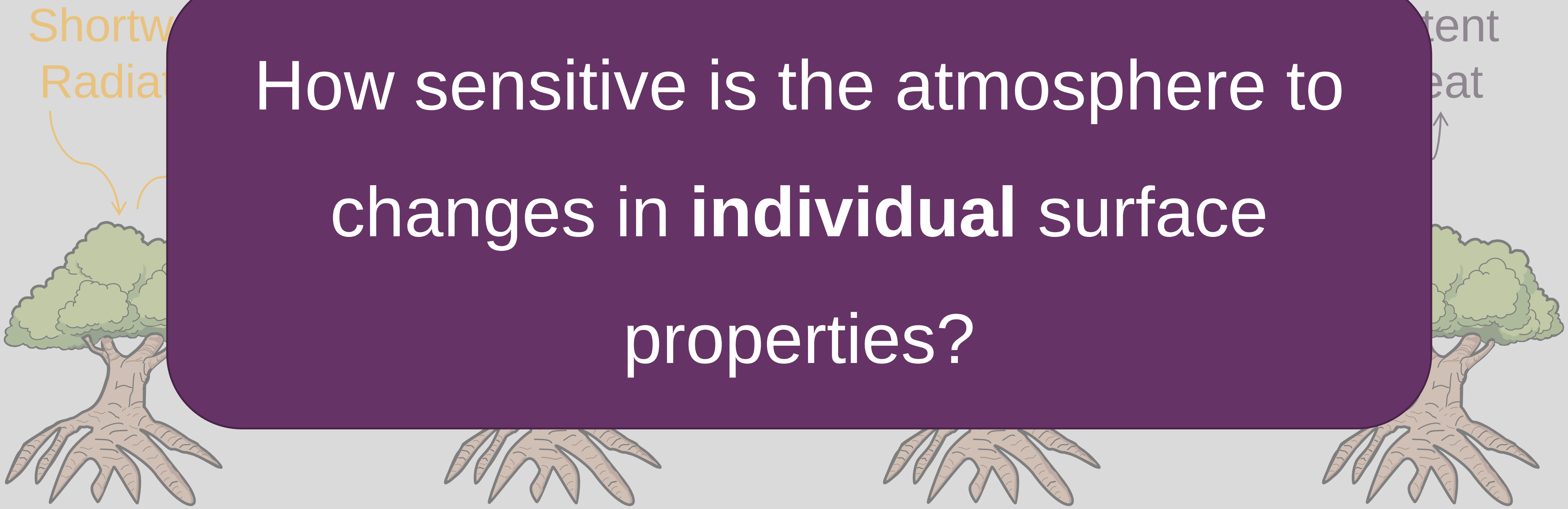
Surface properties influence climate

The land & atmosphere interact through the surface energy budget



The land & atmosphere interact through the surface energy budget





How sensitive is the atmosphere to changes in **individual** surface properties?

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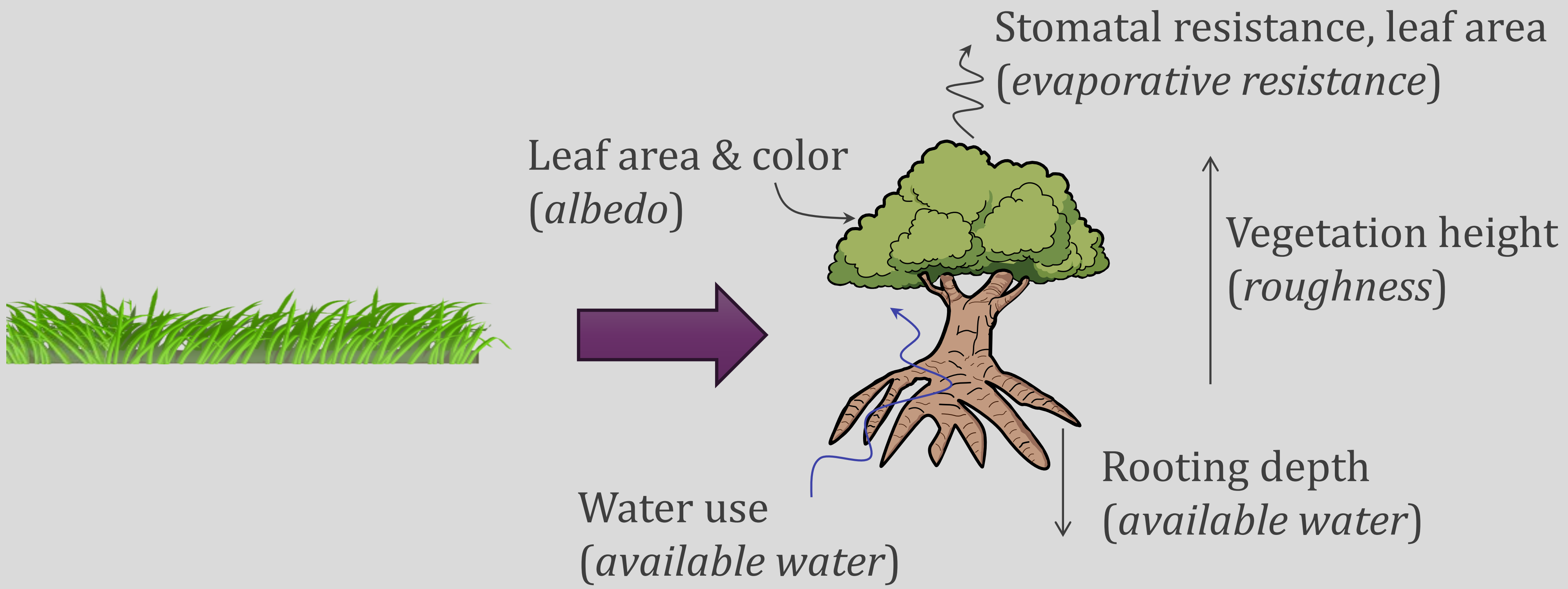
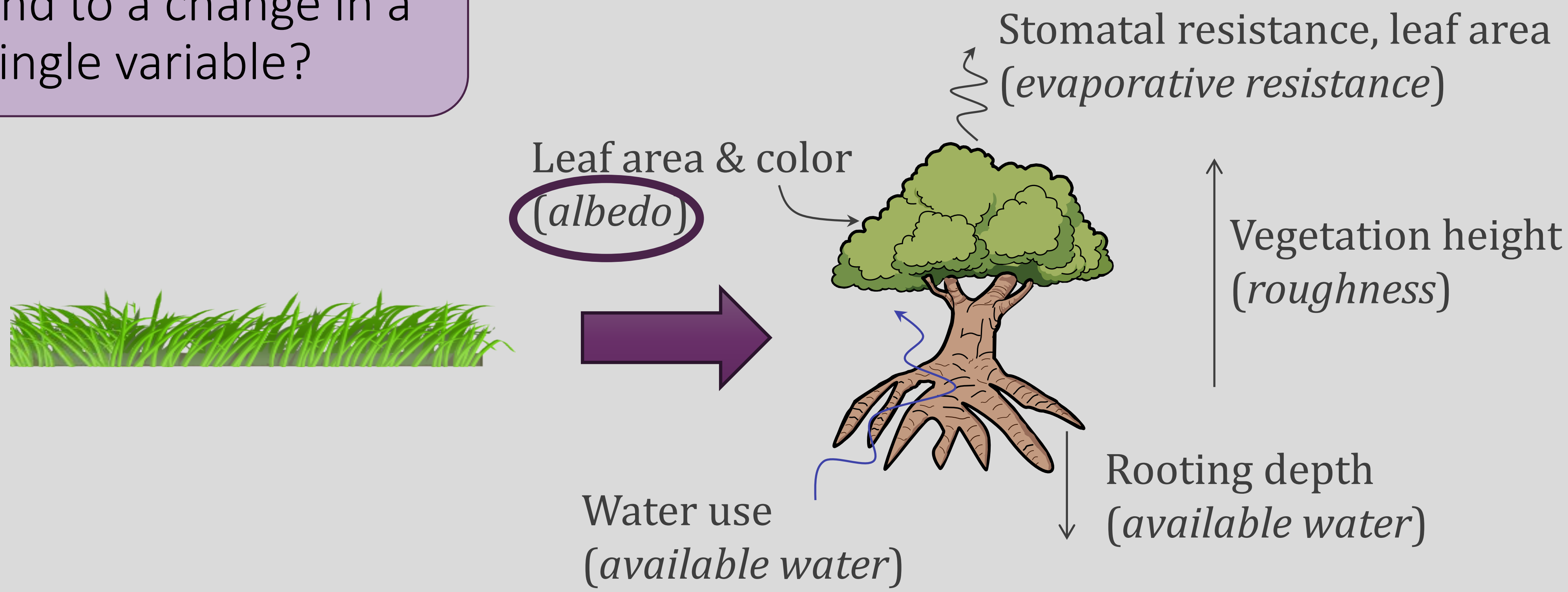
In CLM, many surface properties are **emergent** & **interdependent**



In CLM, many surface properties are **emergent** & **interdependent**

How does the atmosphere respond to a change in a single variable?



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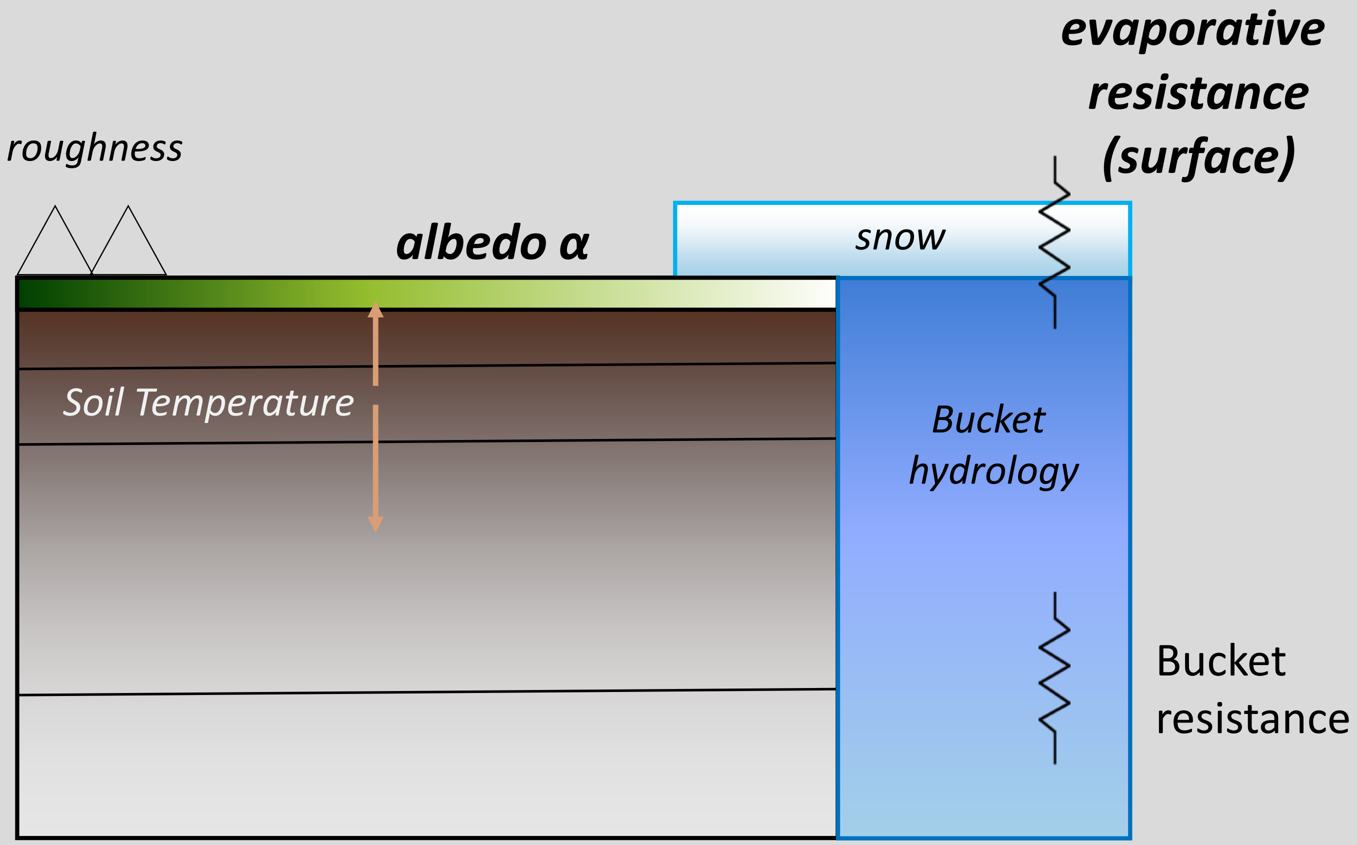
Use a **simple land model** coupled to CESM

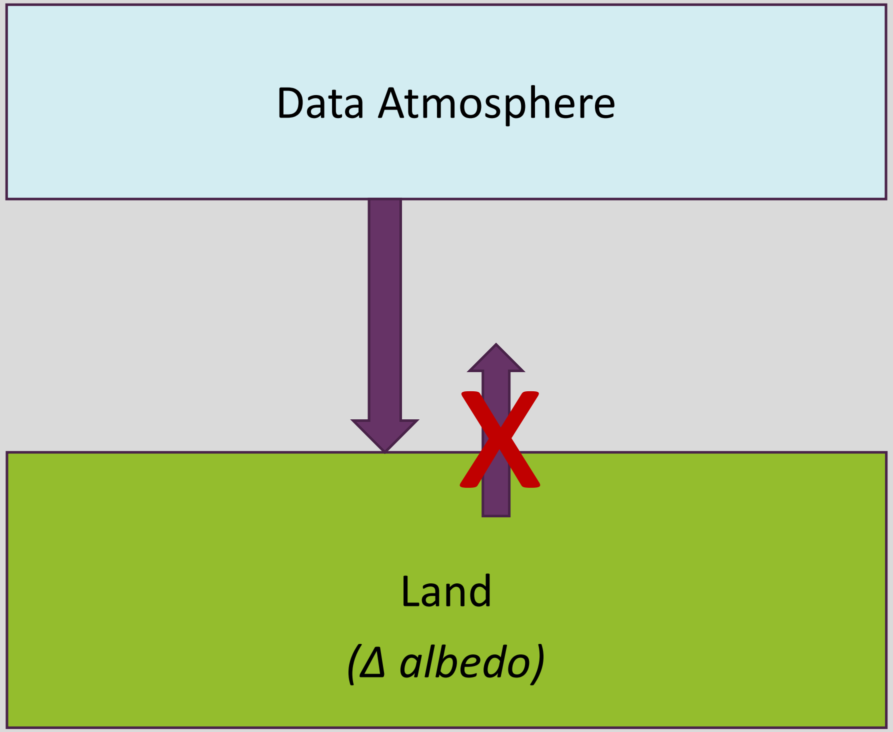
→ Test climate impact of independently changing a single surface property

Coupled to CESM
in place of CLM



Two parts of the total climate response to a surface property change:

Land-only (**forced** response)



Changes in the surface energy budget
uncoupled from the atmosphere

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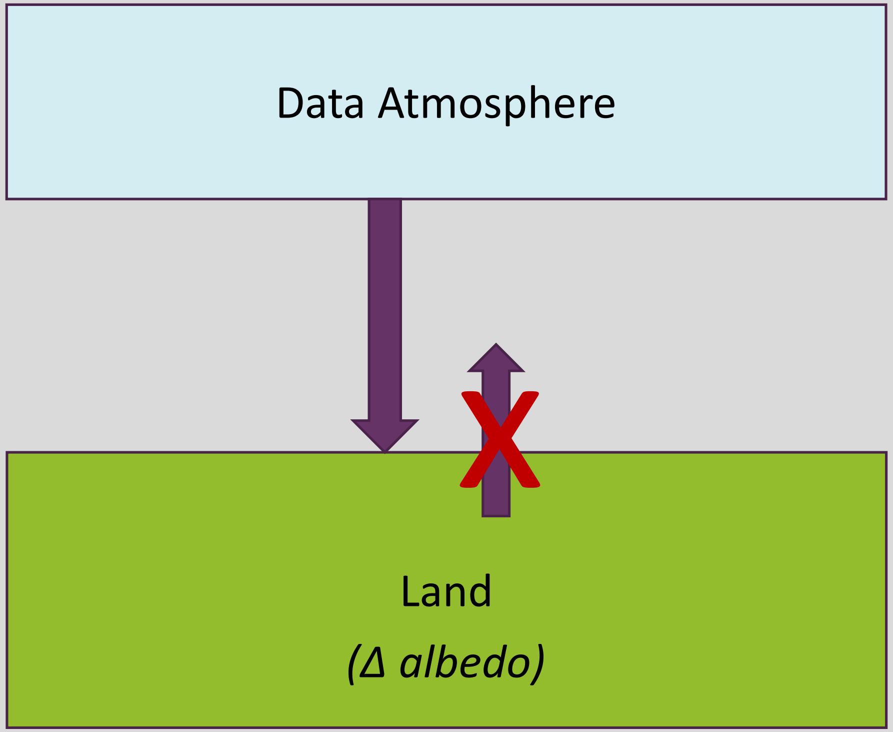
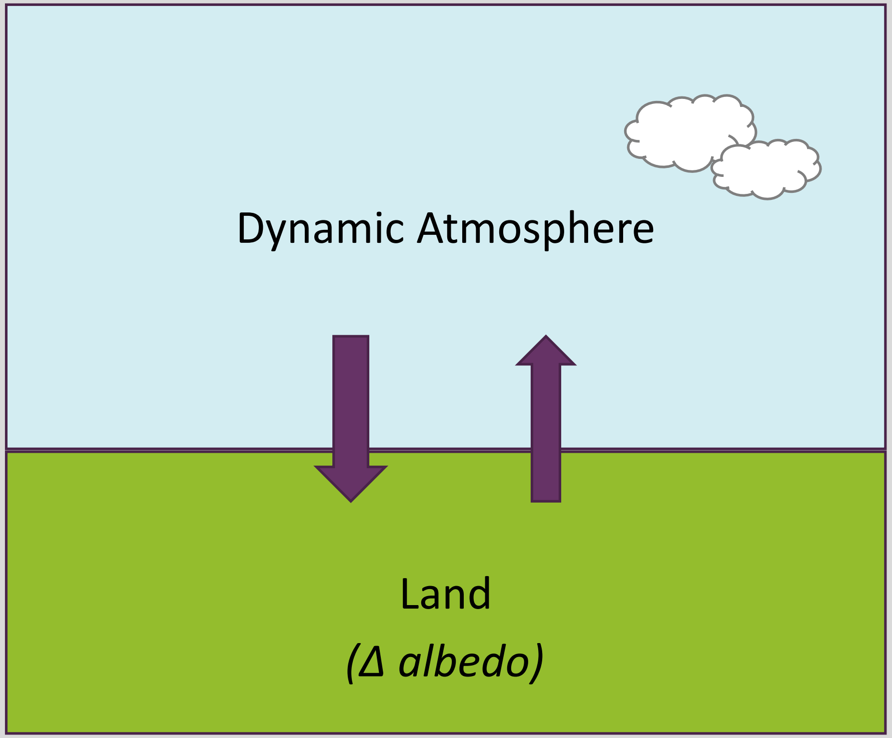


Changes in the surface energy budget uncoupled from the atmosphere

Coupled (Forcing + **Feedbacks**)



Changes in the surface energy budget that include feedbacks from the atmosphere

Consider a global change in land albedo:

$\downarrow$ albedo → $\uparrow$ Absorbed Shortwave Energy (E_{in})

(should have the largest impact where there is lots of sun)

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$\downarrow$ albedo → $\uparrow$ Absorbed Shortwave Energy (E_{in})

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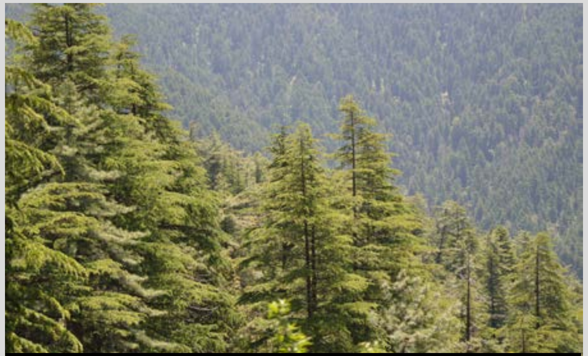
α = 0.1



pine forest

$\Delta\alpha$ = 0.1 →

α = 0.2

grassland

$\Delta\alpha$ = 0.1 →

α = 0.3

dessert

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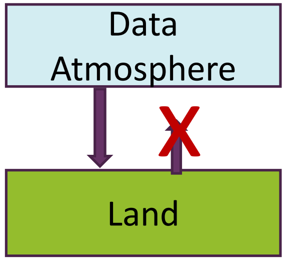
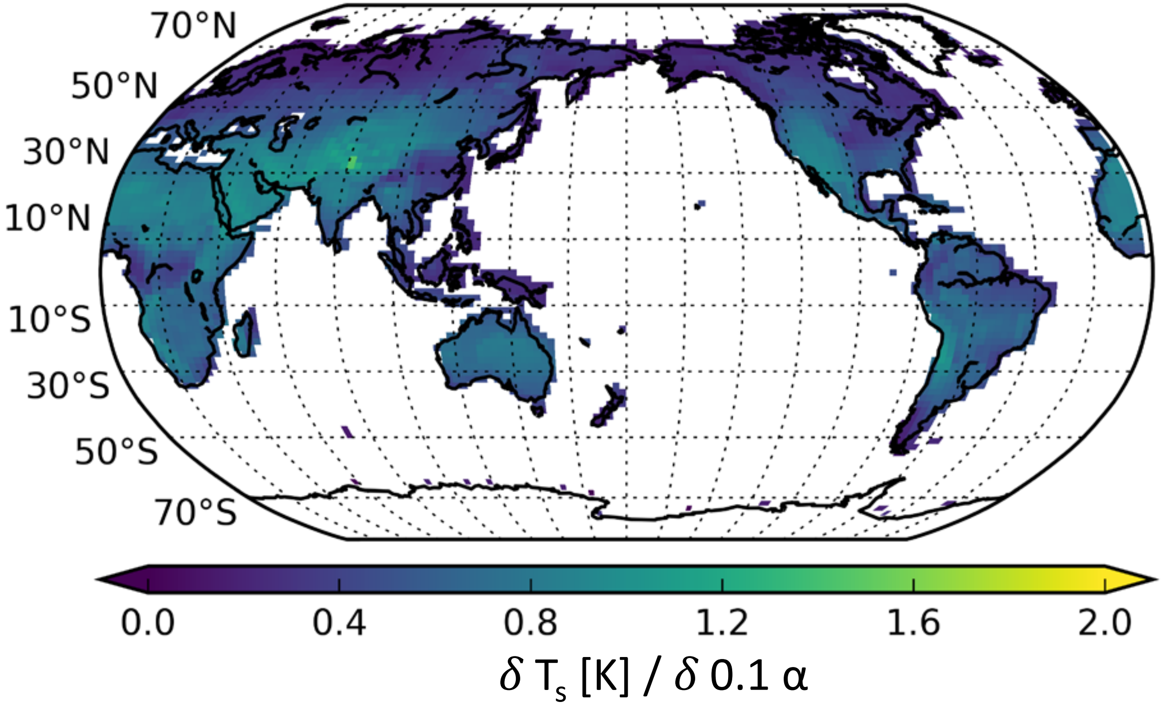
Warming **only** due to changes in the surface energy budget (no atmosphere)



Land only (“Forcing”)



Albedo

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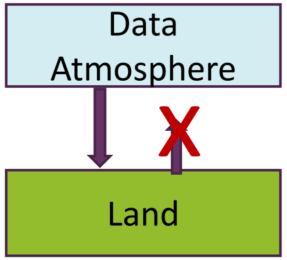
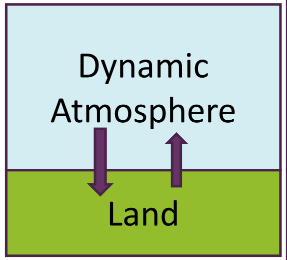
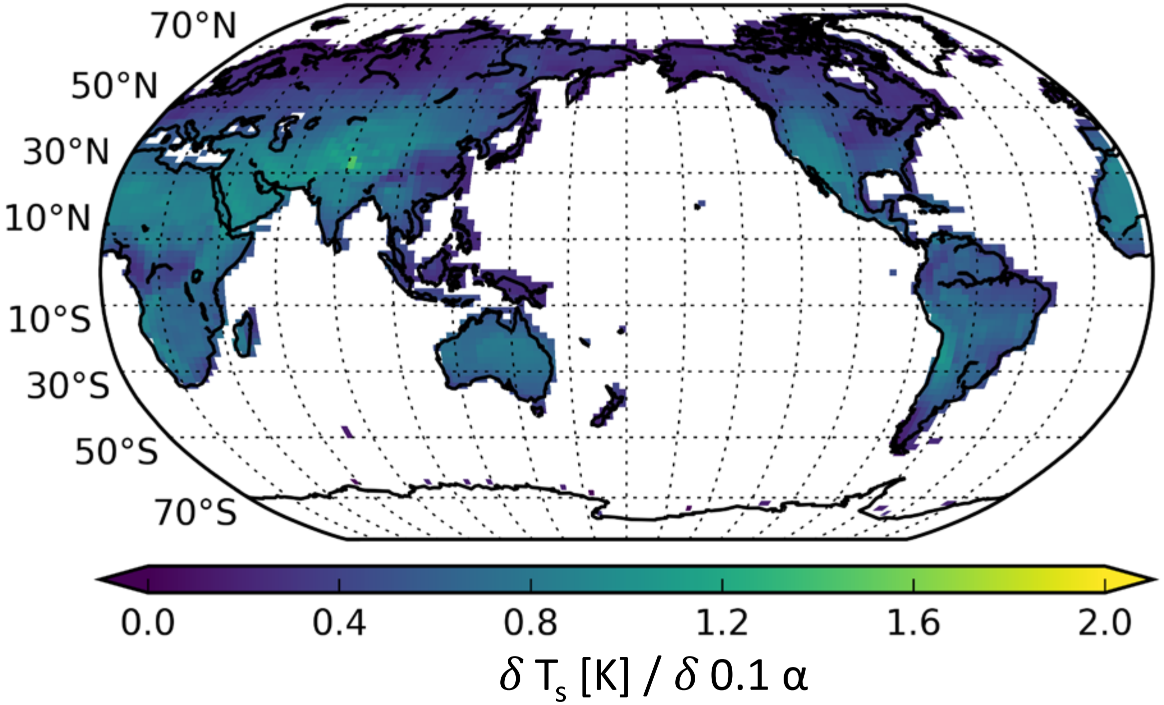
Pattern of warming changes when atmosphere can respond

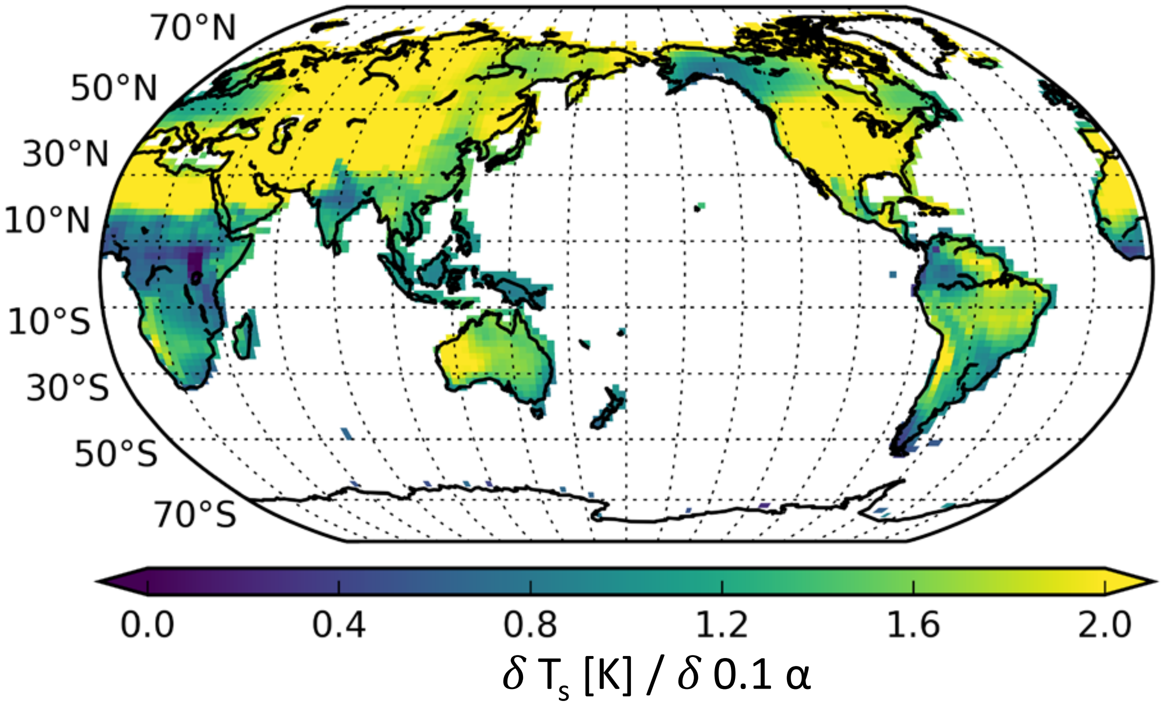




Land only ("Forcing")



Coupled (Feedbacks + Forcing)



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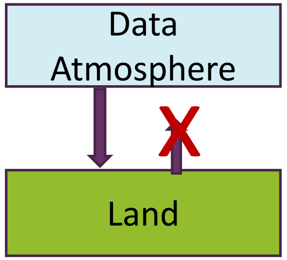
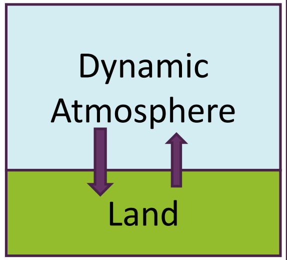
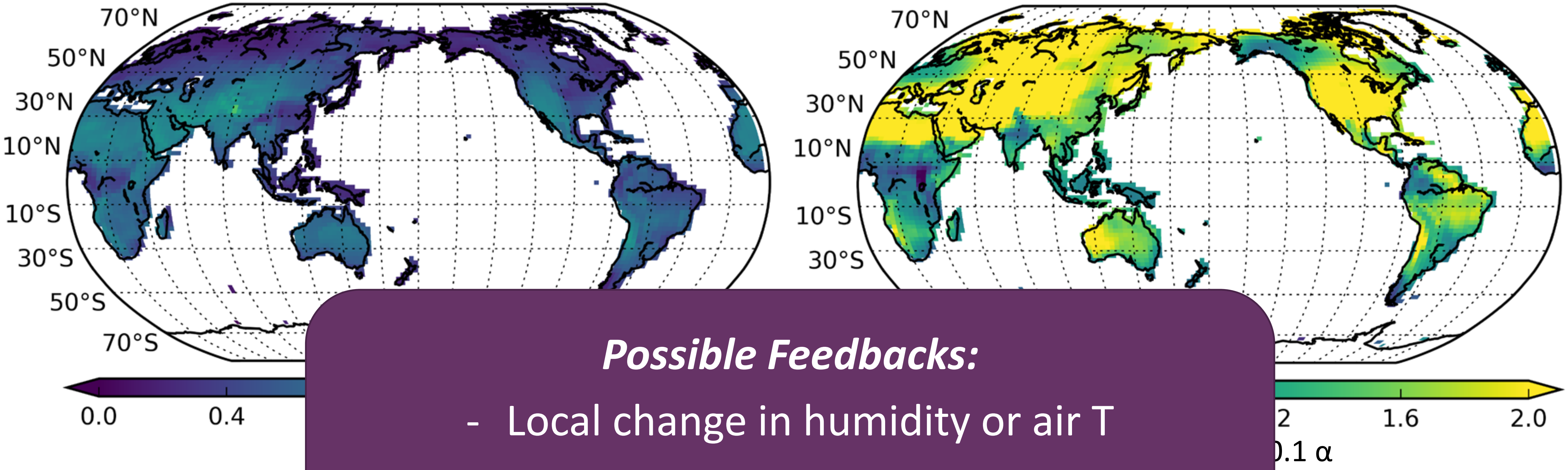


Land only (“Forcing”)

Coupled (Feedbacks + Forcing)





Albedo

Possible Feedbacks:

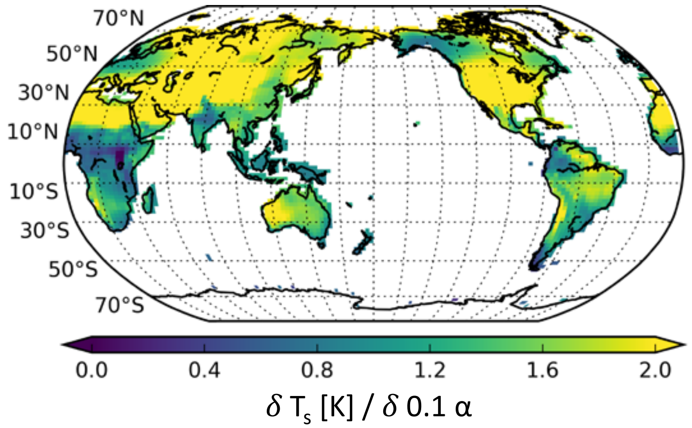
- Local change in humidity or air T
- Change in regional cloud cover
- Global atmospheric circulation

Isolate the warming signal coming from changes in the atmosphere:

Feedback
(Warming due to atmosphere)

=

Coupled (forcing + feedbacks)



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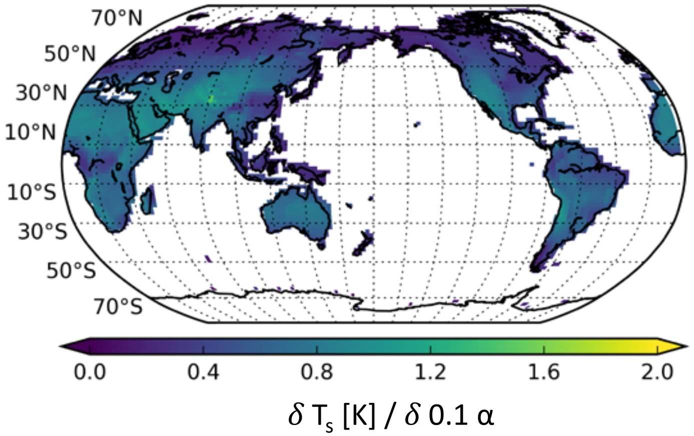
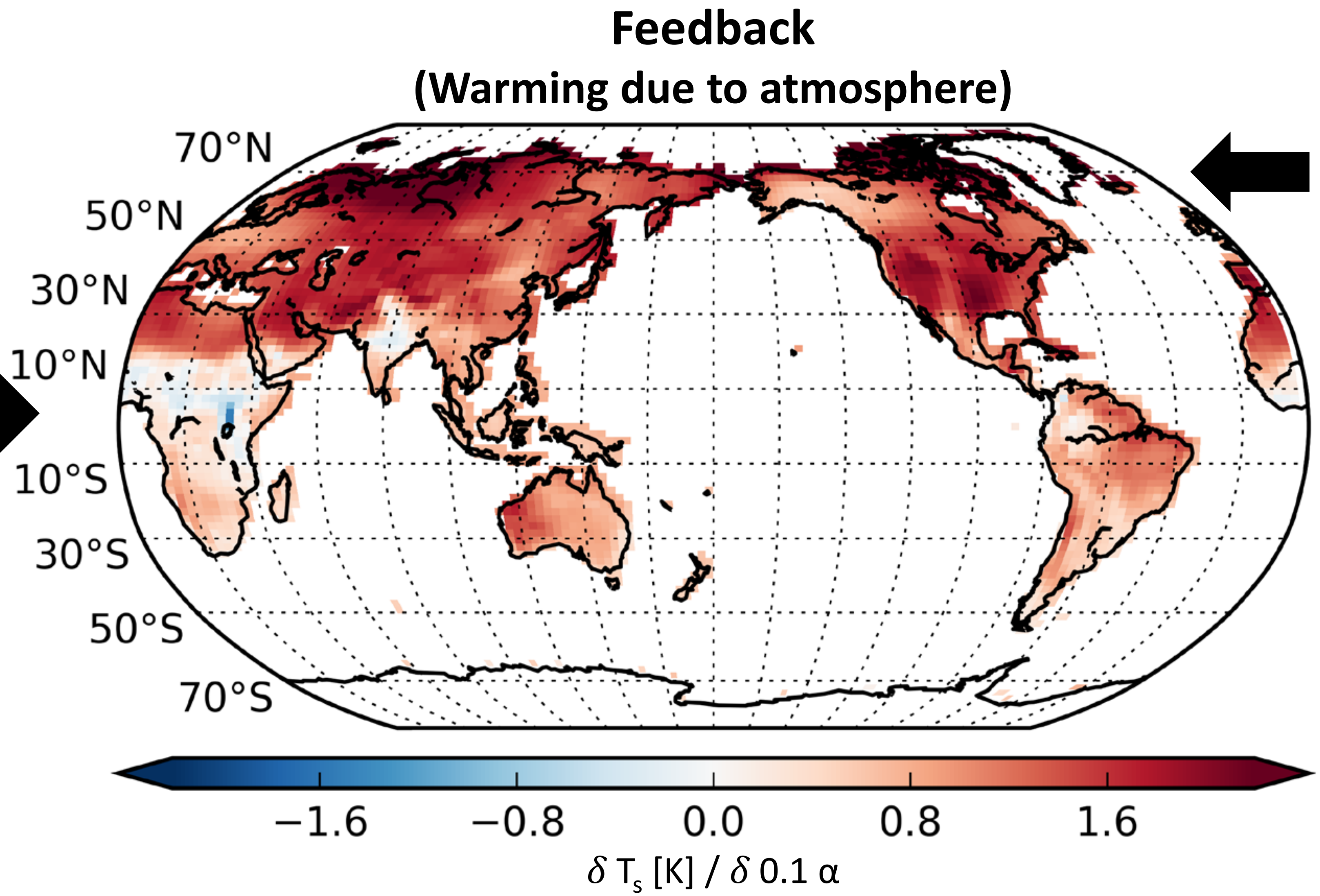
Land only (no feedbacks)



Albedo

Warming signal coming from changes in the atmosphere:

Tropics:
get most of the answer from the surface



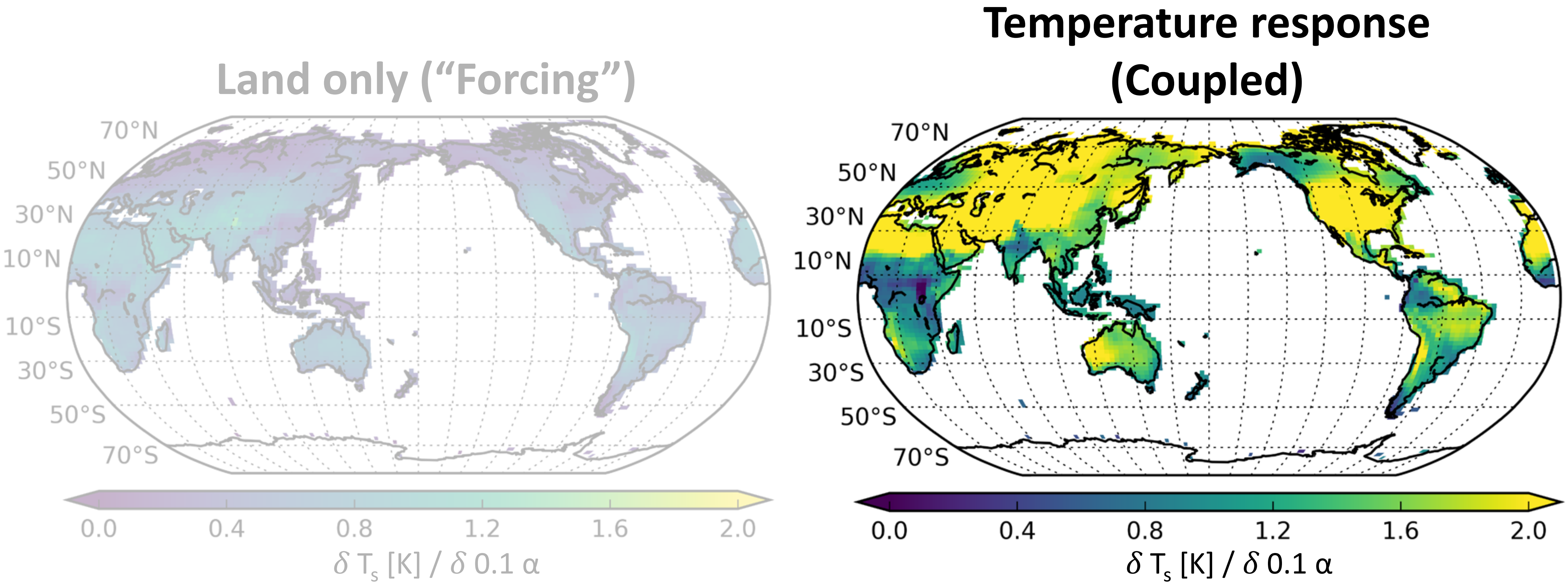
Extra-tropics: lots of warming from atmospheric feedbacks

Albedo

Take Home Point #1:

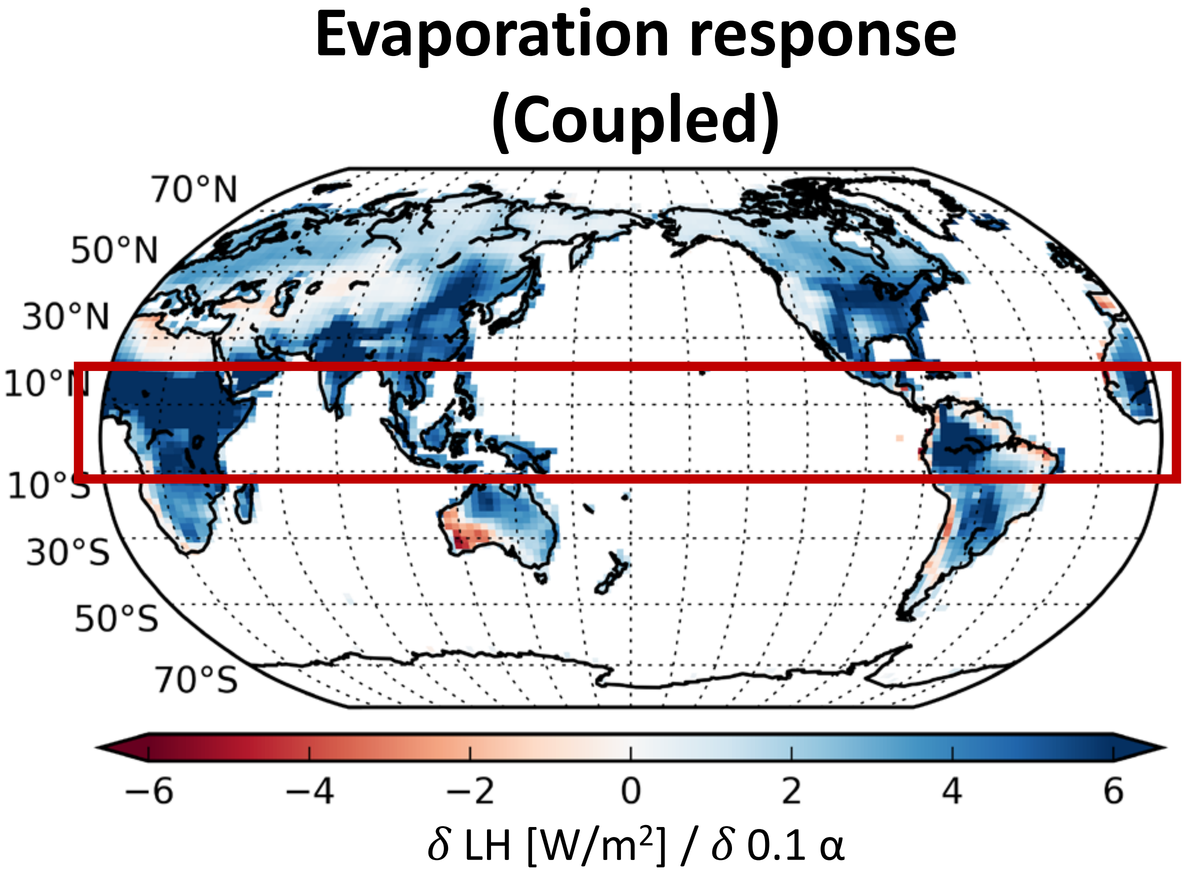
Atmospheric feedbacks play a major role in the extra-tropics in determining the impact of albedo changes on surface temperature

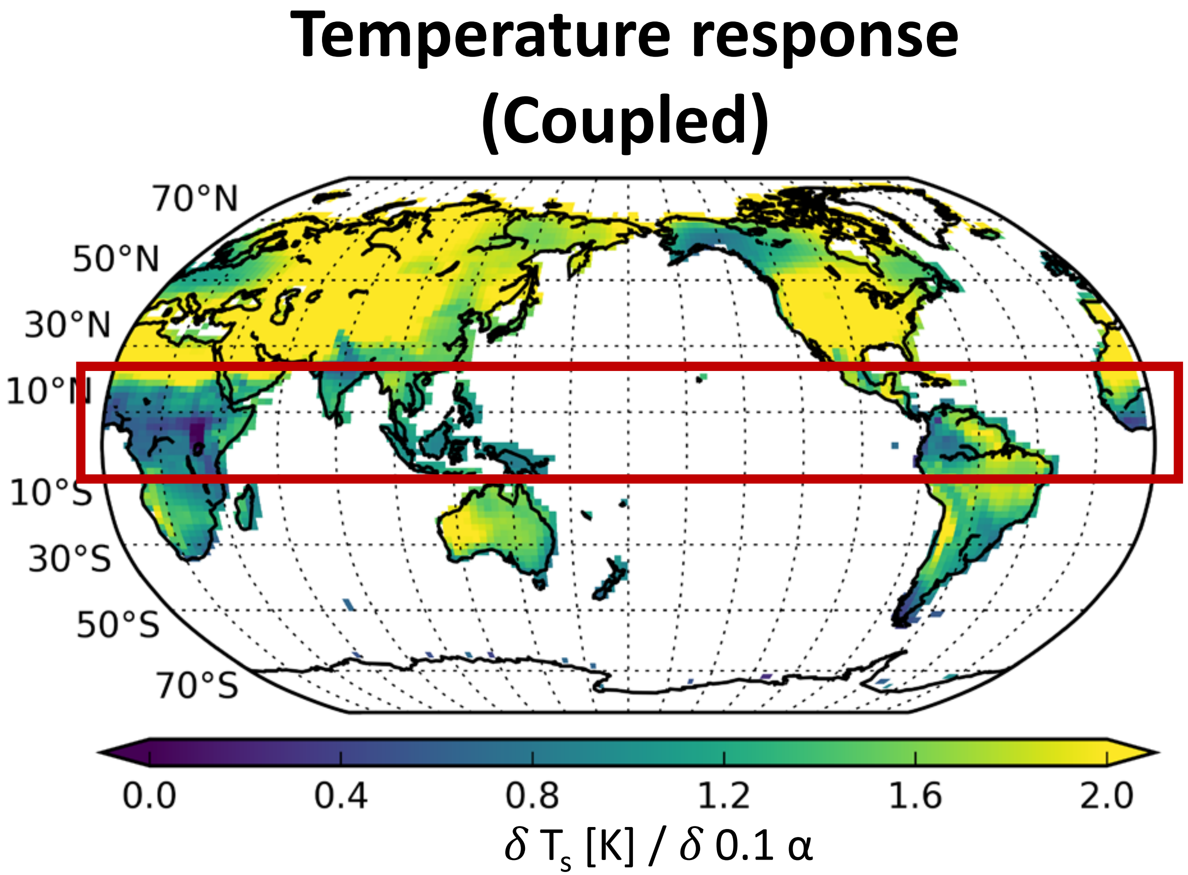
Temperature isn't the whole story…



Albedo

Tropics have small response in T_s, but big change in evaporation





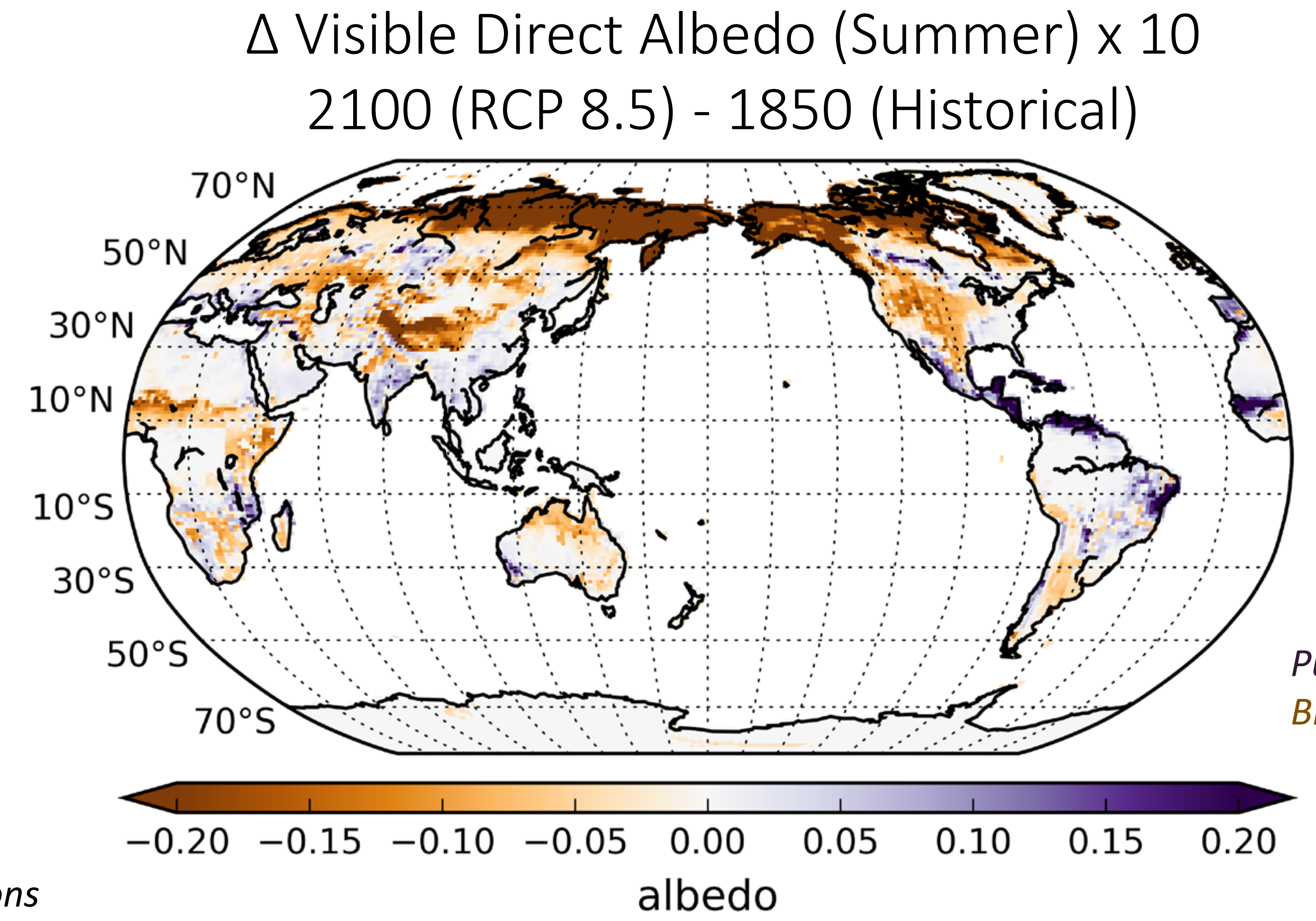
Albedo

Take Home Point #2:

The background climate of a region controls how it responds to a surface change

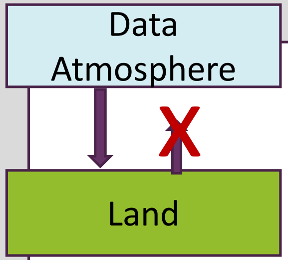
(e.g. tropics don’t warm much when surface darkens, because there is lots of water available to evaporate)

Atmospheric feedbacks for a more realistic pattern of albedo change

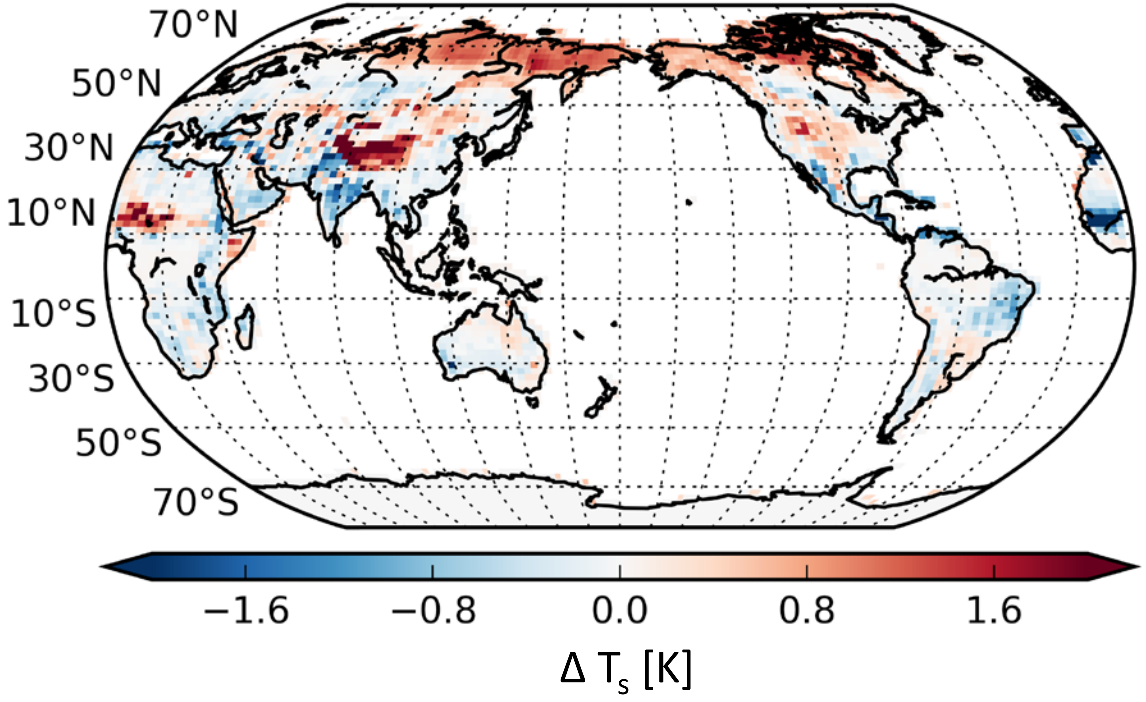


Purple – brighter in future
Brown – darker in future

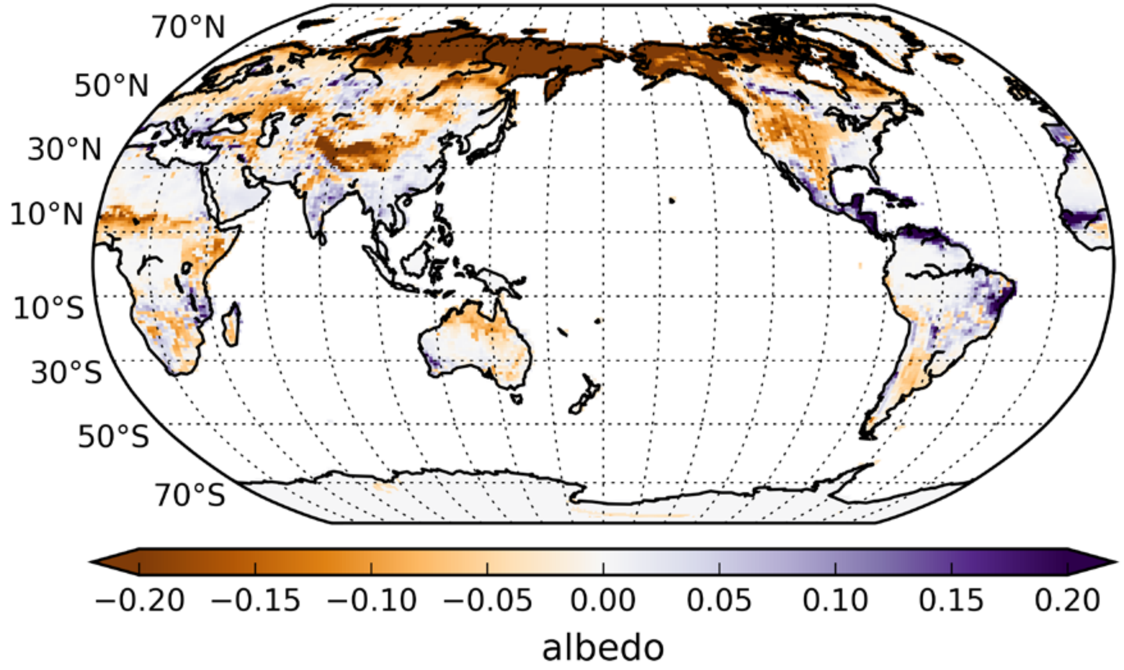
From CESM CMIP5 simulations

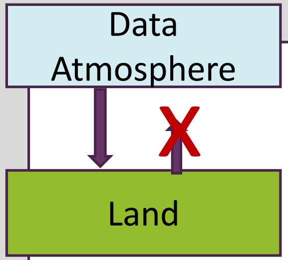


Land only (no feedbacks)



Albedo pattern:





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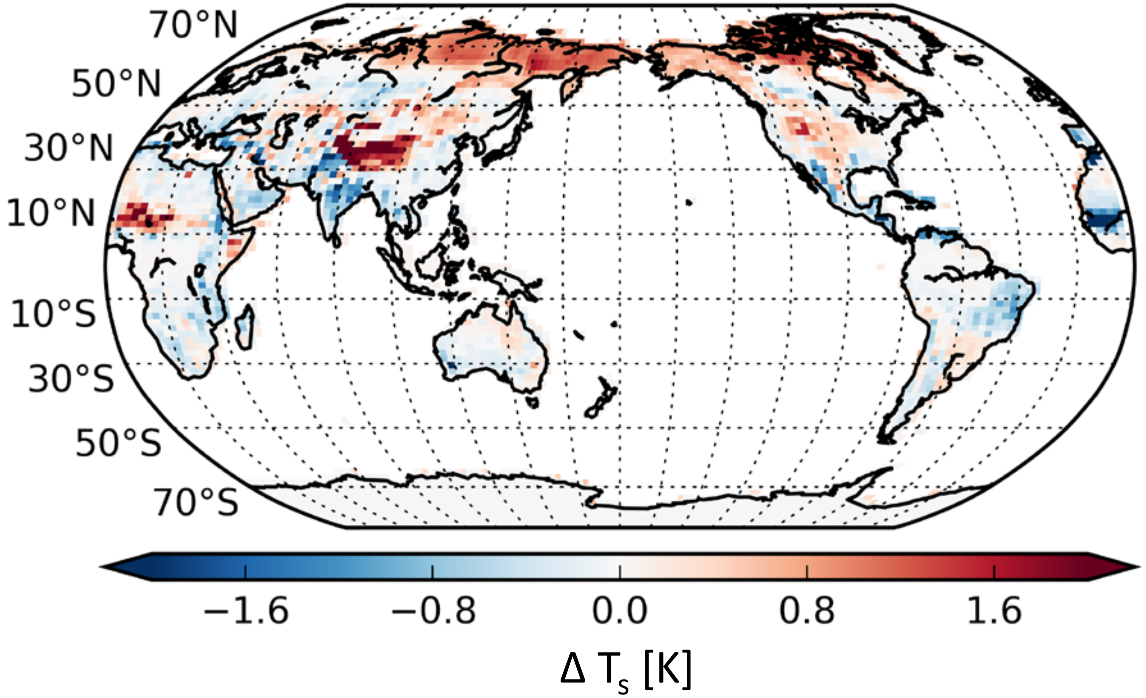
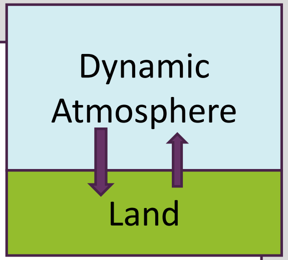
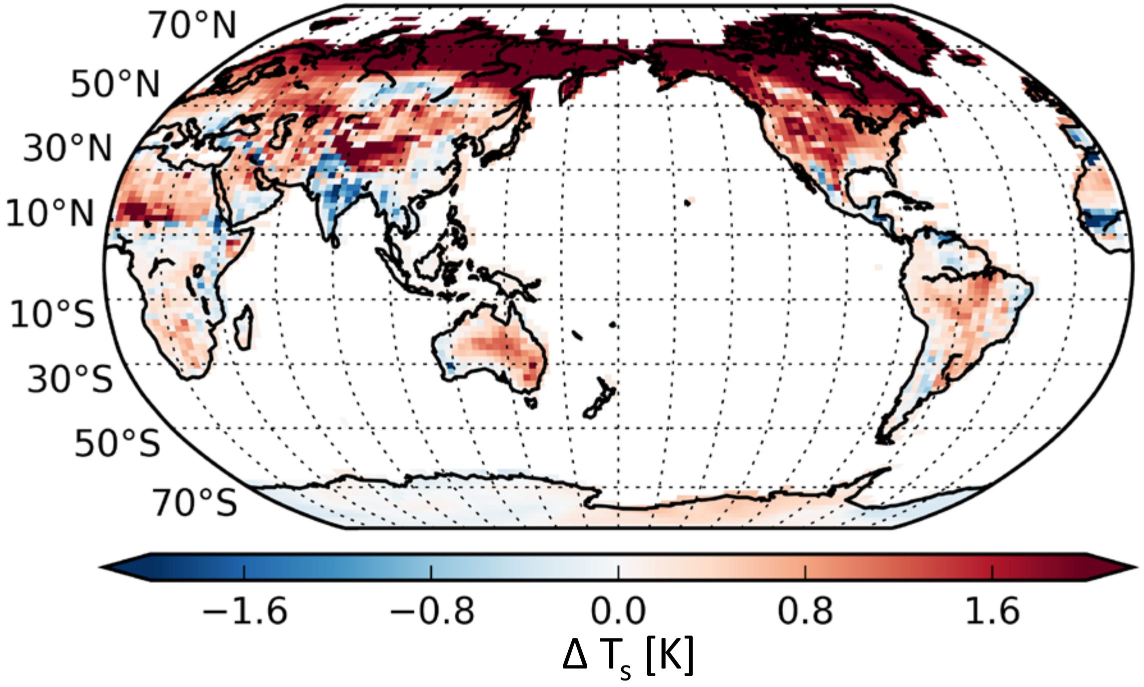




Coupled
(includes feedbacks)

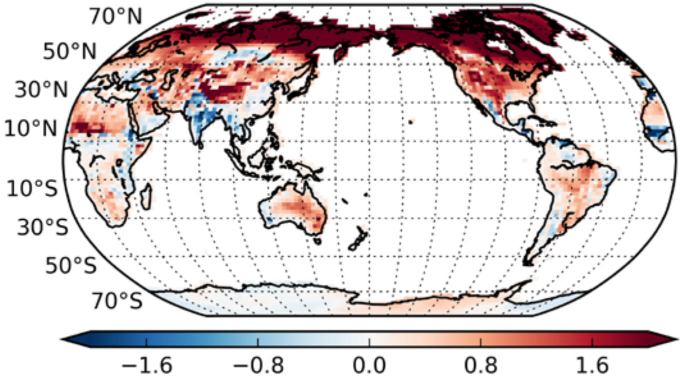


Isolate the warming signal coming from changes in the atmosphere:

Feedback
(Extra warming due to atmosphere)

=

Coupled (feedbacks)



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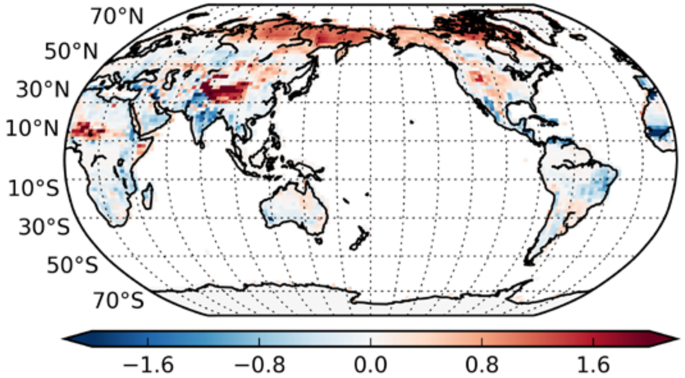
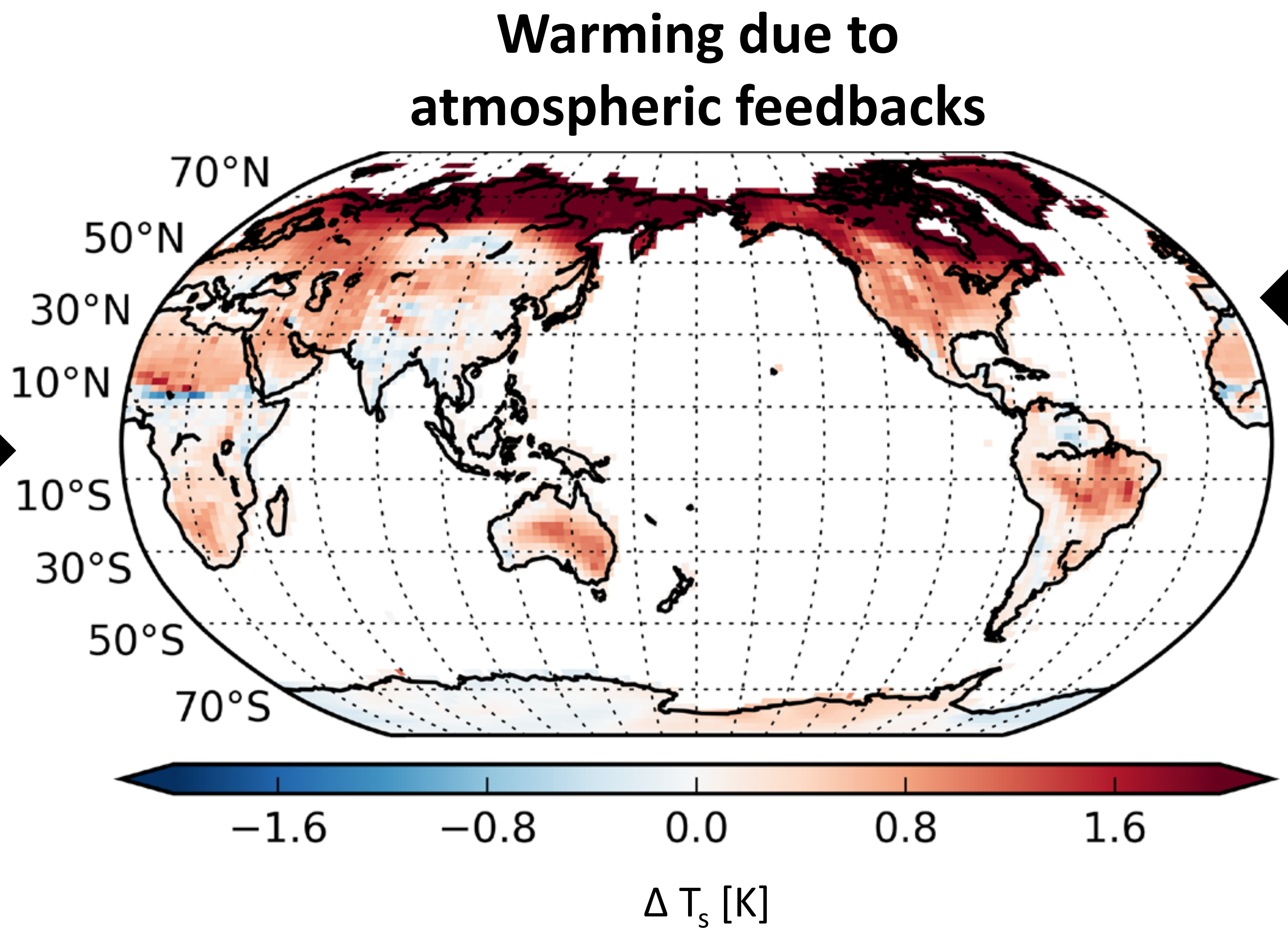
Land only (no feedbacks)



Albedo

Isolate the warming signal coming from changes in the atmosphere:

Tropics:
Weak atmospheric feedback component



Extra-tropics:
strong atmospheric feedback

Take Home Point #3:

Even with a more realistic *pattern* of albedo change, the warming due to atmospheric feedbacks is much broader in scale than the imposed albedo change

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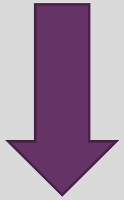
Even with a more realistic *pattern* of albedo change, the warming due to atmospheric feedbacks is much broader in scale than the imposed albedo change

What are these atmospheric feedbacks?

Atmospheric feedback example:
Cloud loss in response to increased evaporative resistance

Darker surface
(↓ albedo)



↑ Warmer

Atmospheric feedback example:
Cloud loss in response to increased evaporative resistance

Darker surface
(↓ albedo)

↓

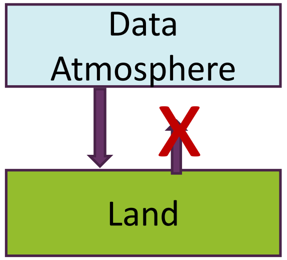
↑ Warmer

Harder to evaporate
(↑ resistance)

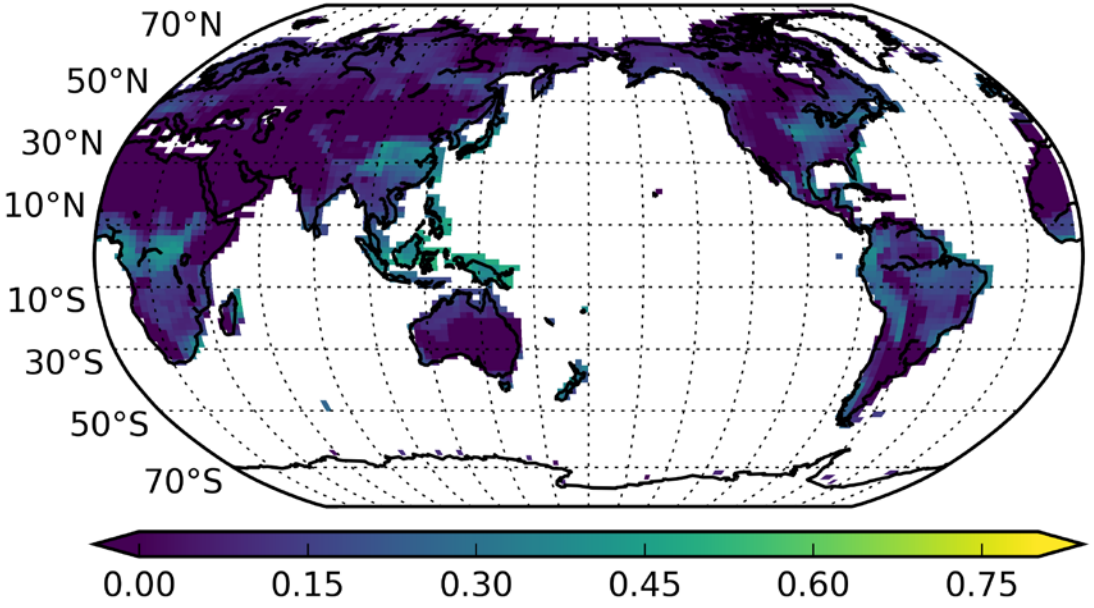
↓

↑ Warmer

Increased surface resistance (to evaporation) leads to warming



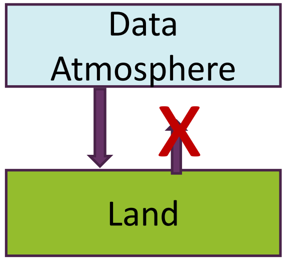
Land only (Forcing)

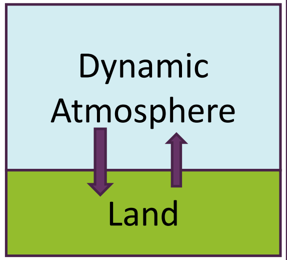


δ T_s [K] / δ 50 [s/m] r_s

Evaporative Resistance

Increased surface resistance (to evaporation) leads to warming
Pattern & magnitude change when atmosphere responds





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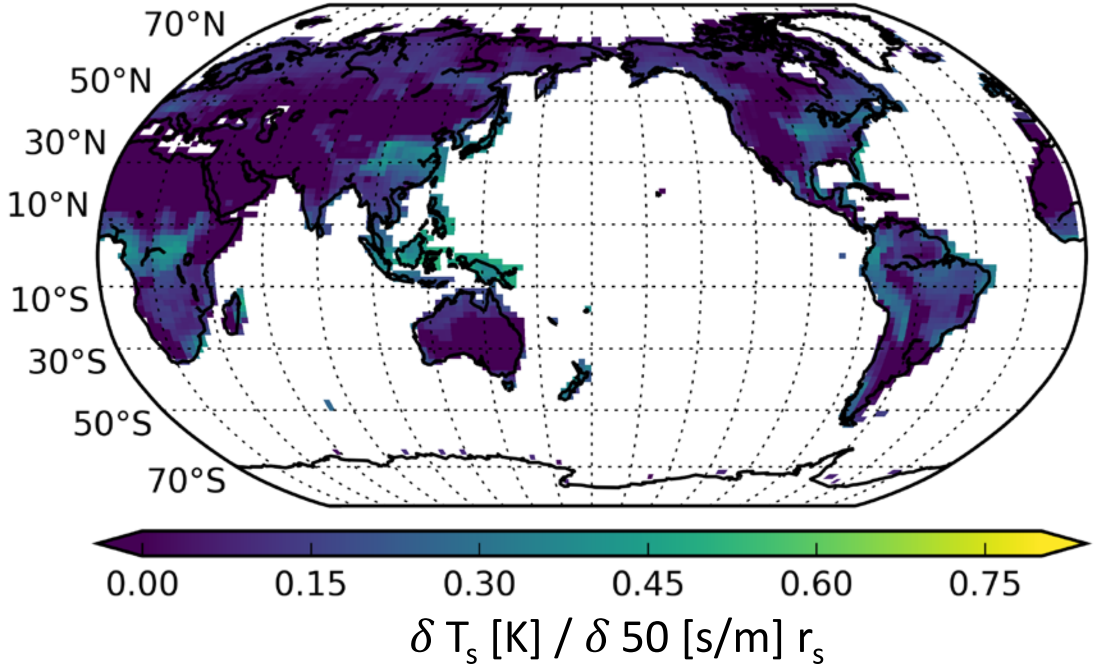
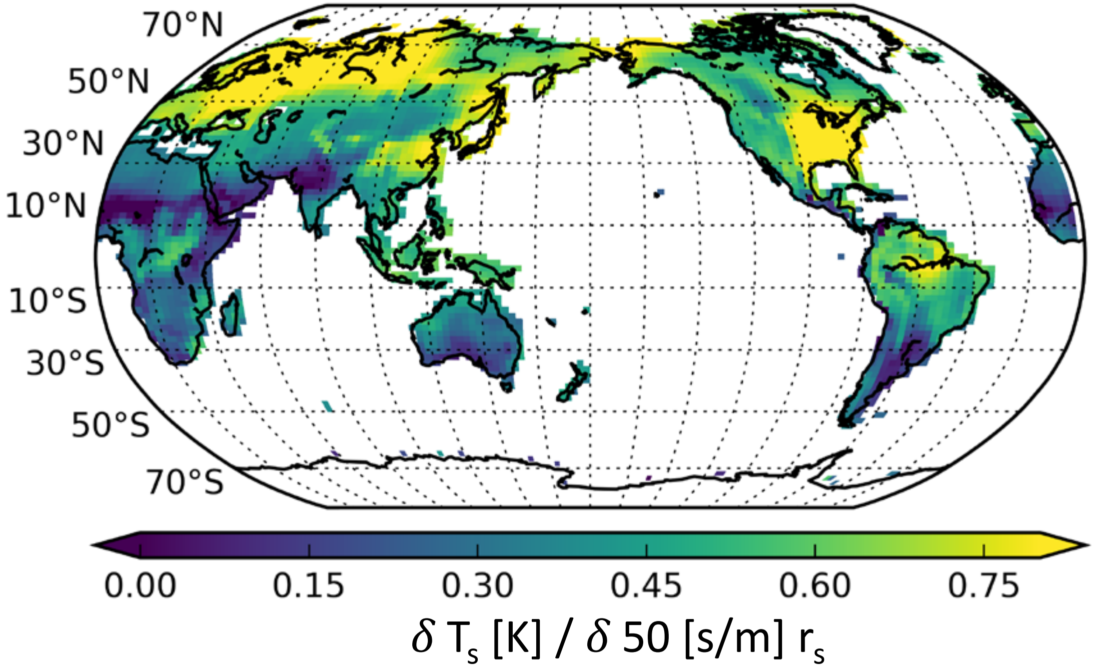
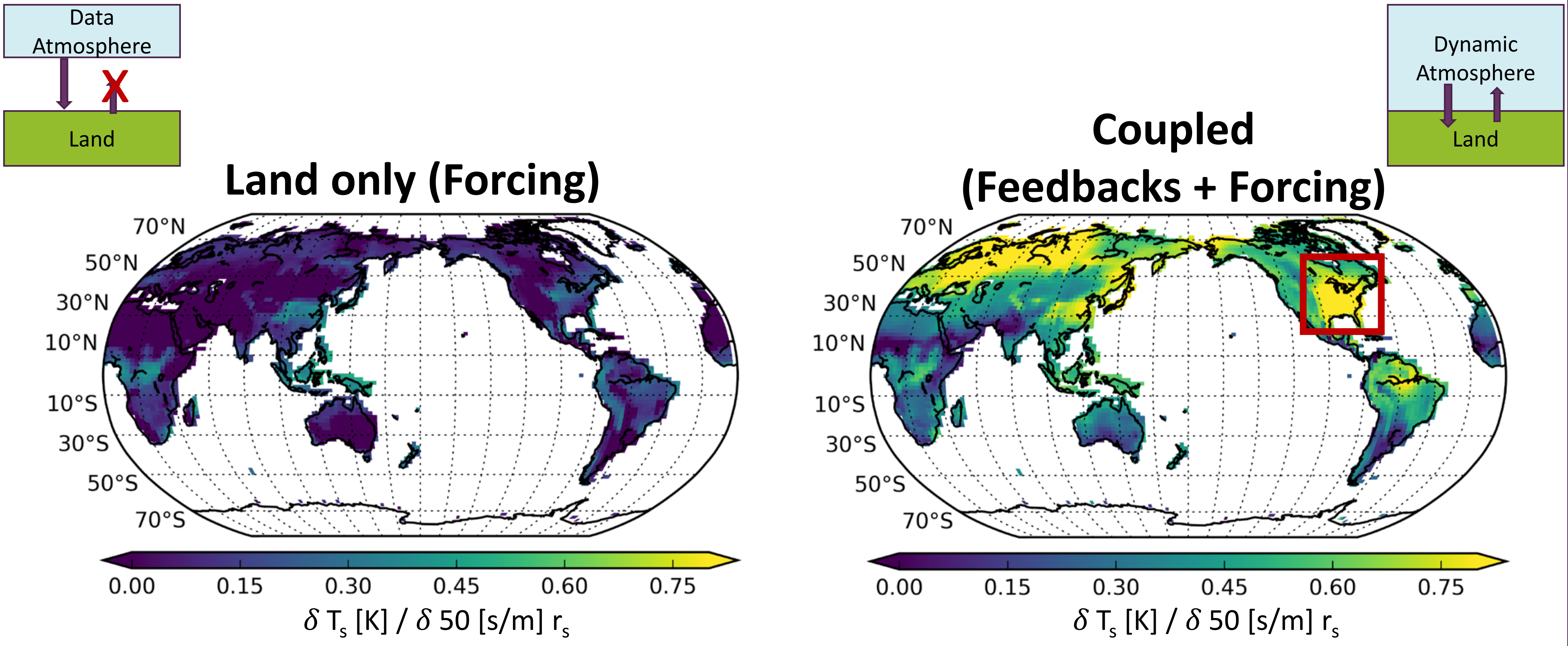


Coupled (Feedbacks + Forcing)



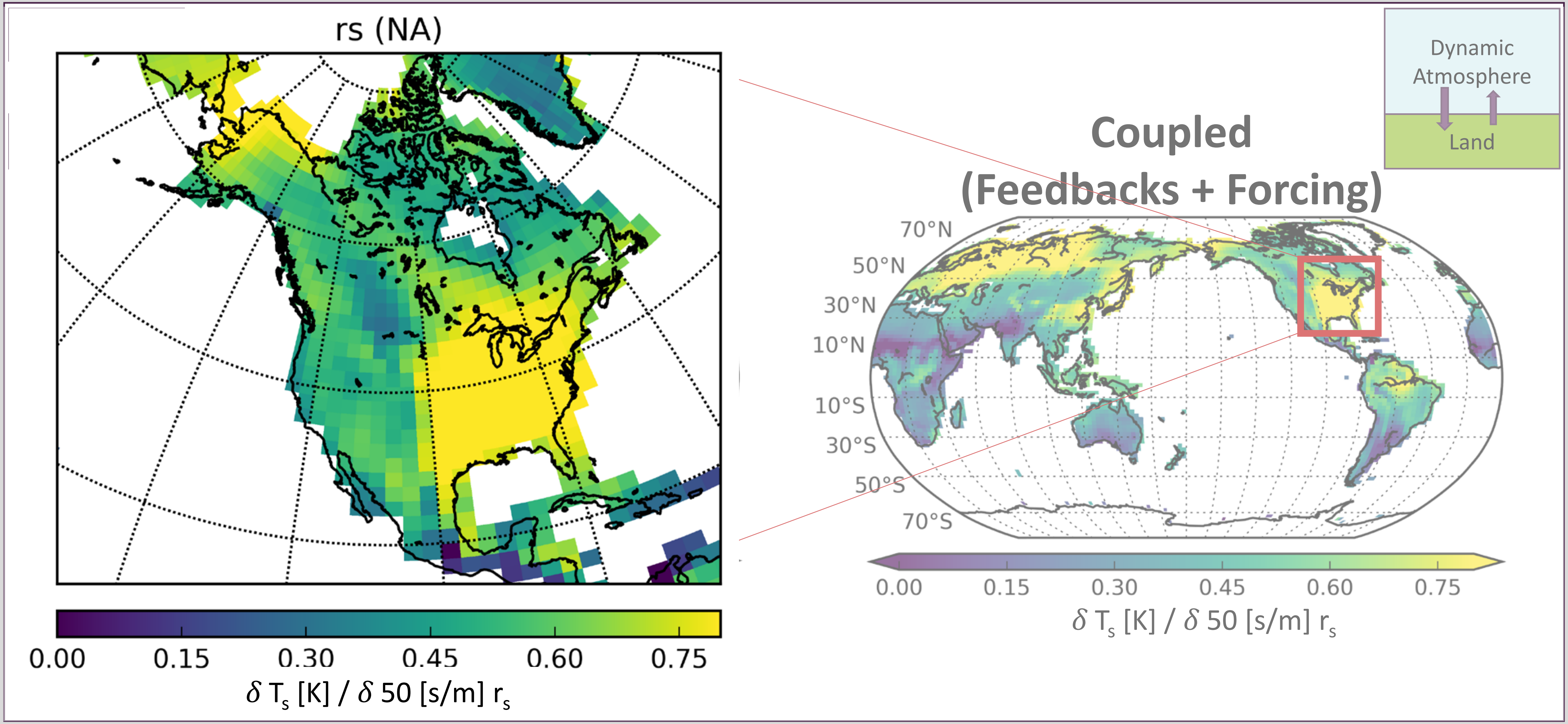
Evaporative Resistance

Increased surface resistance (to evaporation) leads to warming
Pattern & magnitude change when atmosphere responds



Evaporative Resistance

Increased surface resistance (to evaporation) leads to warming
Pattern & magnitude change when atmosphere responds



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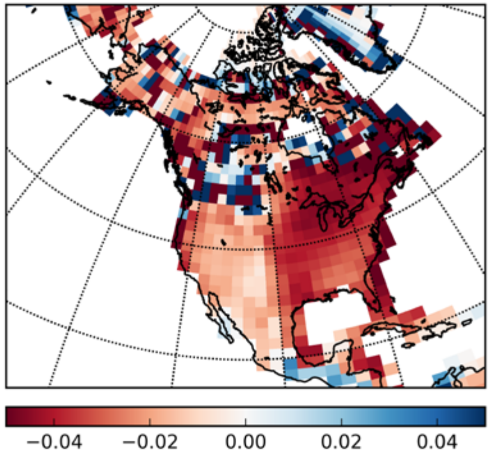
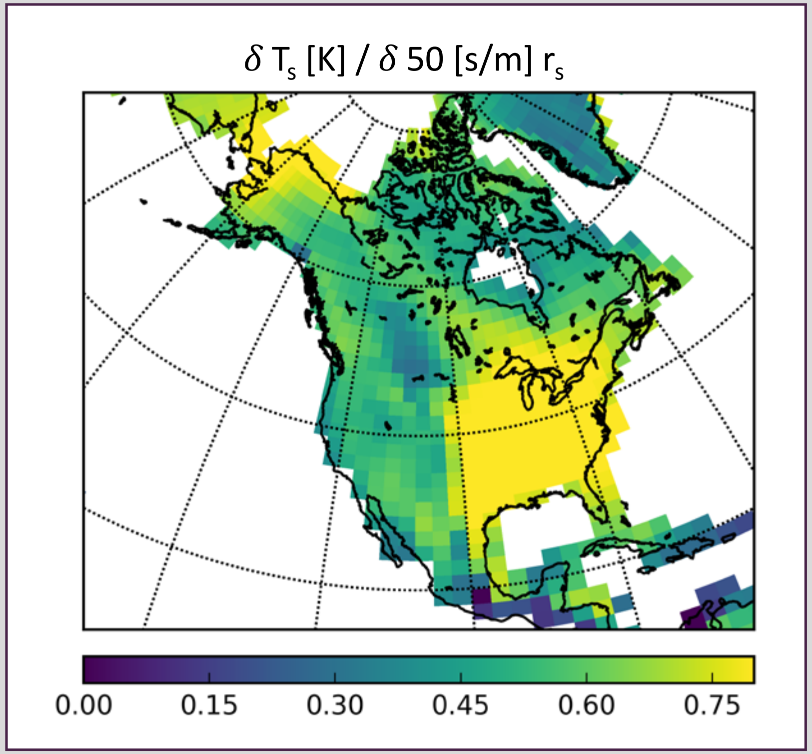
Atmospheric feedback responsible for big temperature response to changing surface resistance

↑ resistance
=
↓ evaporative fraction



δ Evap Frac / δ 50 [s/m] r_s



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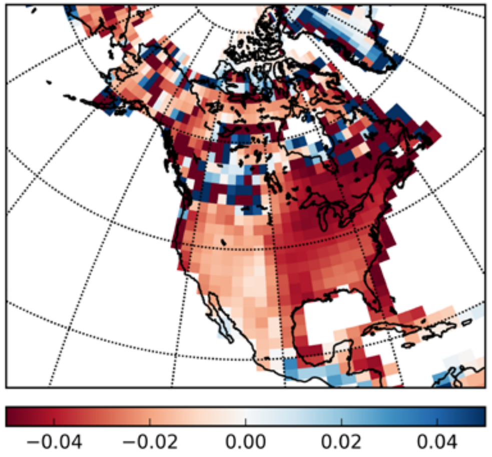
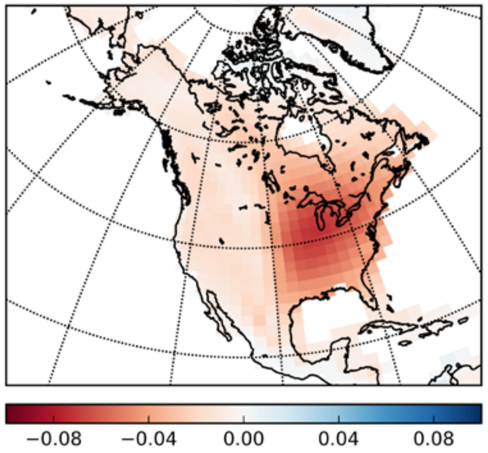


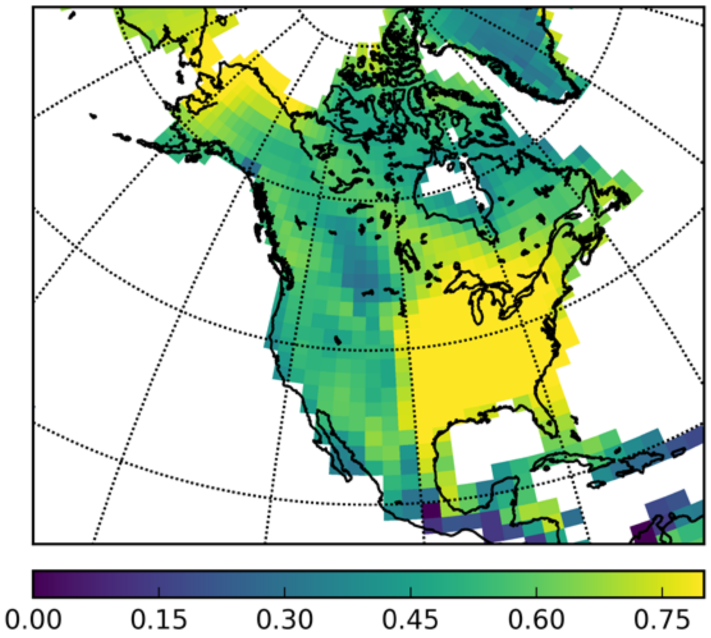
δ Evap Frac / δ 50 [s/m] r_s

↓ evaporative fraction
=
↓ low clouds



δ Low Cloud / δ 50 [s/m] r_s

δ T_s [K] / δ 50 [s/m] r_s



Atmospheric feedback responsible for big temperature response to changing surface resistance

↑ resistance
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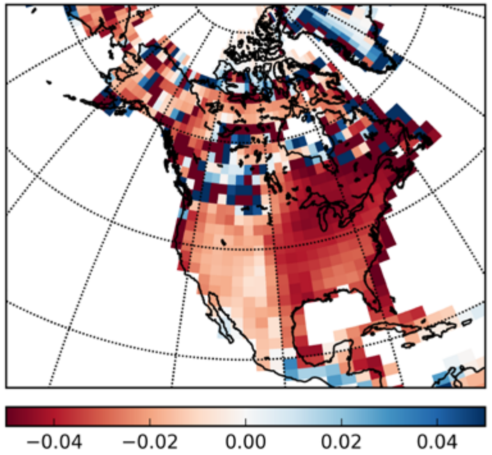
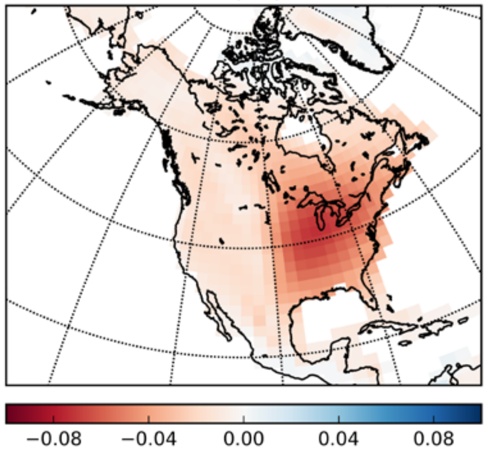


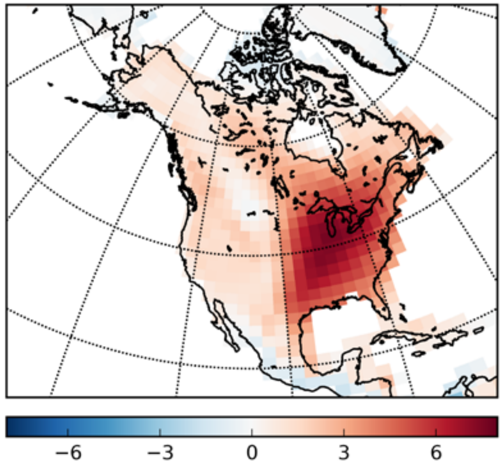
δ Evap Frac / δ 50 [s/m] r_s

↓ evaporative fraction
=
↓ low clouds



δ Low Cloud / δ 50 [s/m] r_s

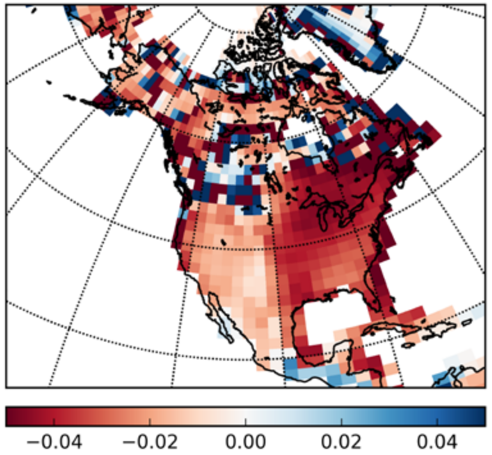
↓ low clouds
=
↑ sun reaching ground



δ Sw_{net} / δ 50 [s/m] r_s

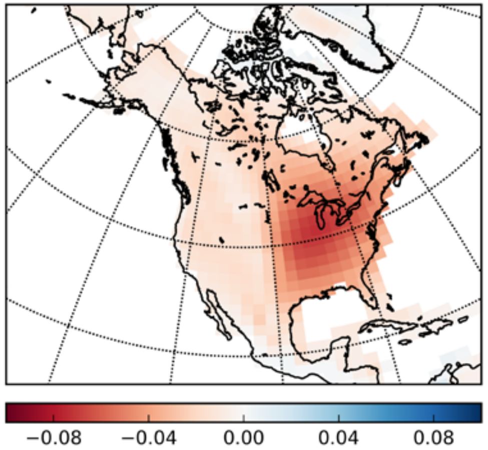
Atmospheric feedback responsible for big temperature response to changing surface resistance

↑ resistance
=
↓ evaporative fraction



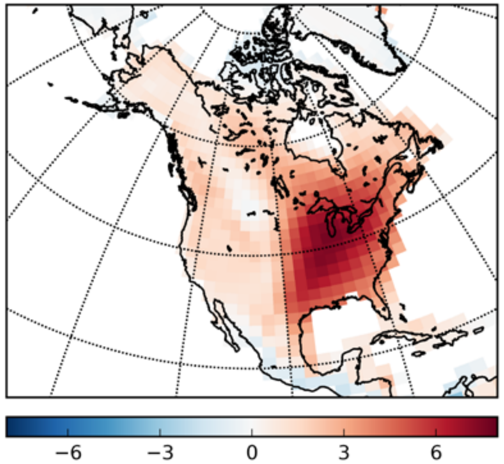
δ Evap Frac / δ 50 [s/m] r_s

↓ evaporative fraction
=
↓ low clouds



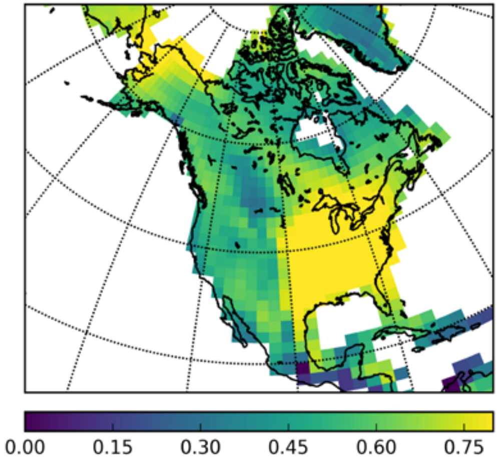
δ Low Cloud / δ 50 [s/m] r_s

↓ low clouds
=
↑ sun reaching ground



δ Sw_{net} / δ 50 [s/m] r_s

↑ sun reaching ground
=
↑ surface T



δ T_s / δ 50 [s/m] r_s

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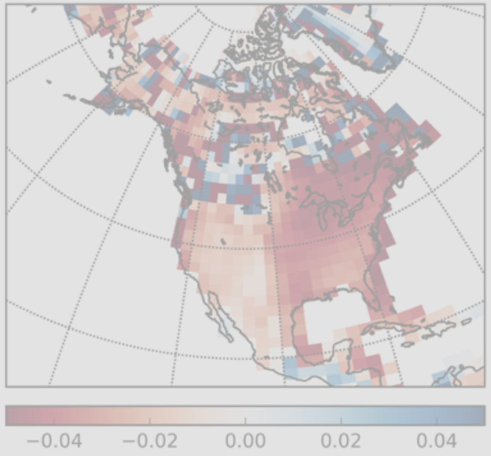
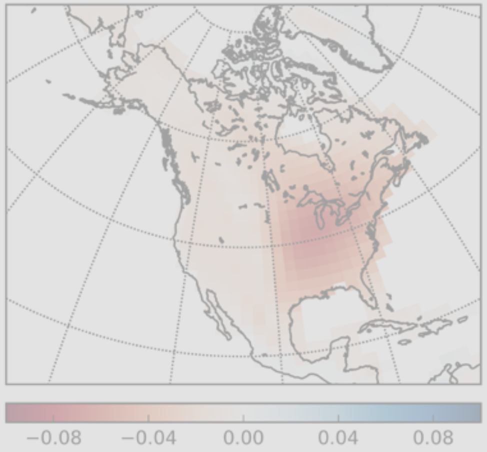
Warming signal here is caused by an **atmospheric feedback** in response to the surface change, not **directly** by the surface change itself

↑ resistance
=
↓ evaporative fraction



δ Evap Frac / δ 50 [s/m] r_s

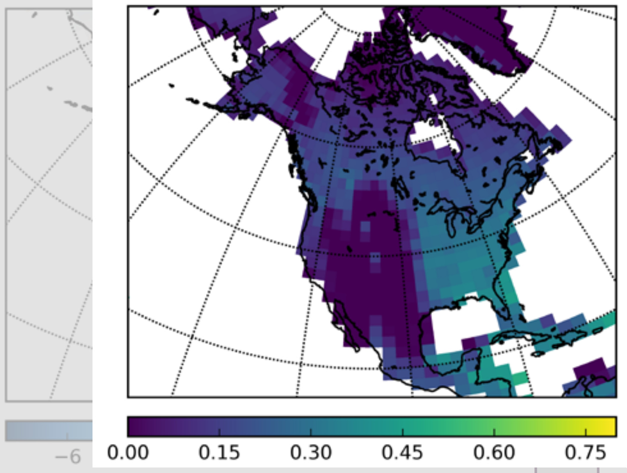
↓ evaporative fraction
=
↓ low clouds



δ Low Cloud / δ 50 [s/m] r_s

↓ low clouds
=
↑ sun reaching ground

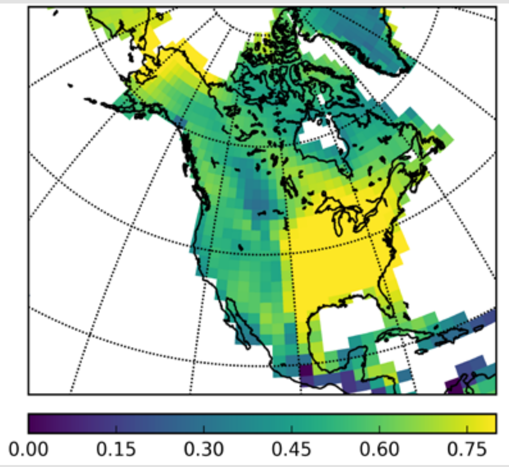
offline



δ Sw_{net} / δ 50 [s/m] r_s

↑ sun reaching ground
=
↑ surface T

coupled



δ T_s / δ 50 [s/m] r_s

Take Home Point #4:

Atmospheric feedbacks (e.g. **cloud** responses) can be very regionally specific

Summary:

The climate implications of a change in surface property are very different, both spatially and in magnitude, if you do/don't account for **atmospheric feedbacks** between the land surface and the atmosphere

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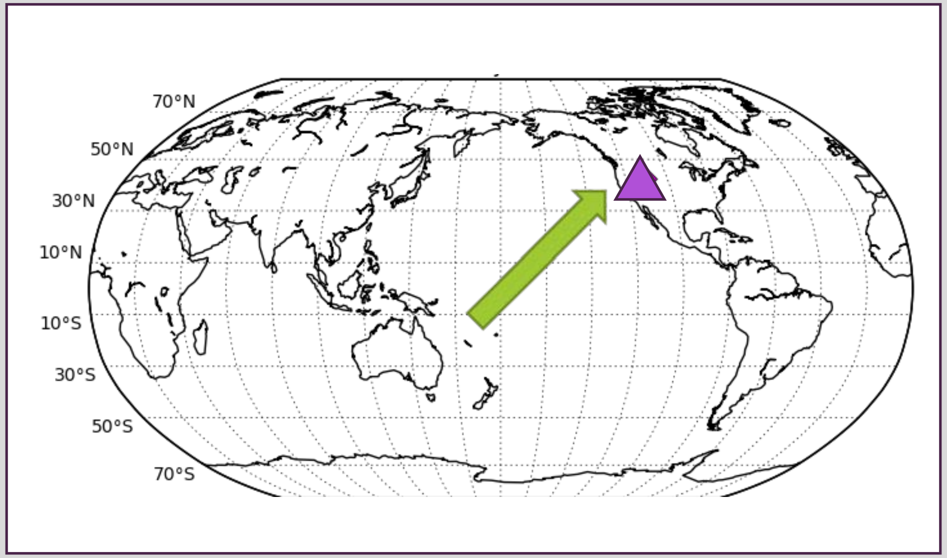
Funding from: NSF-1553715 , NSERC-PGSD3-487470-2016

Computing support from CISL for the Cheyenne supercomputer

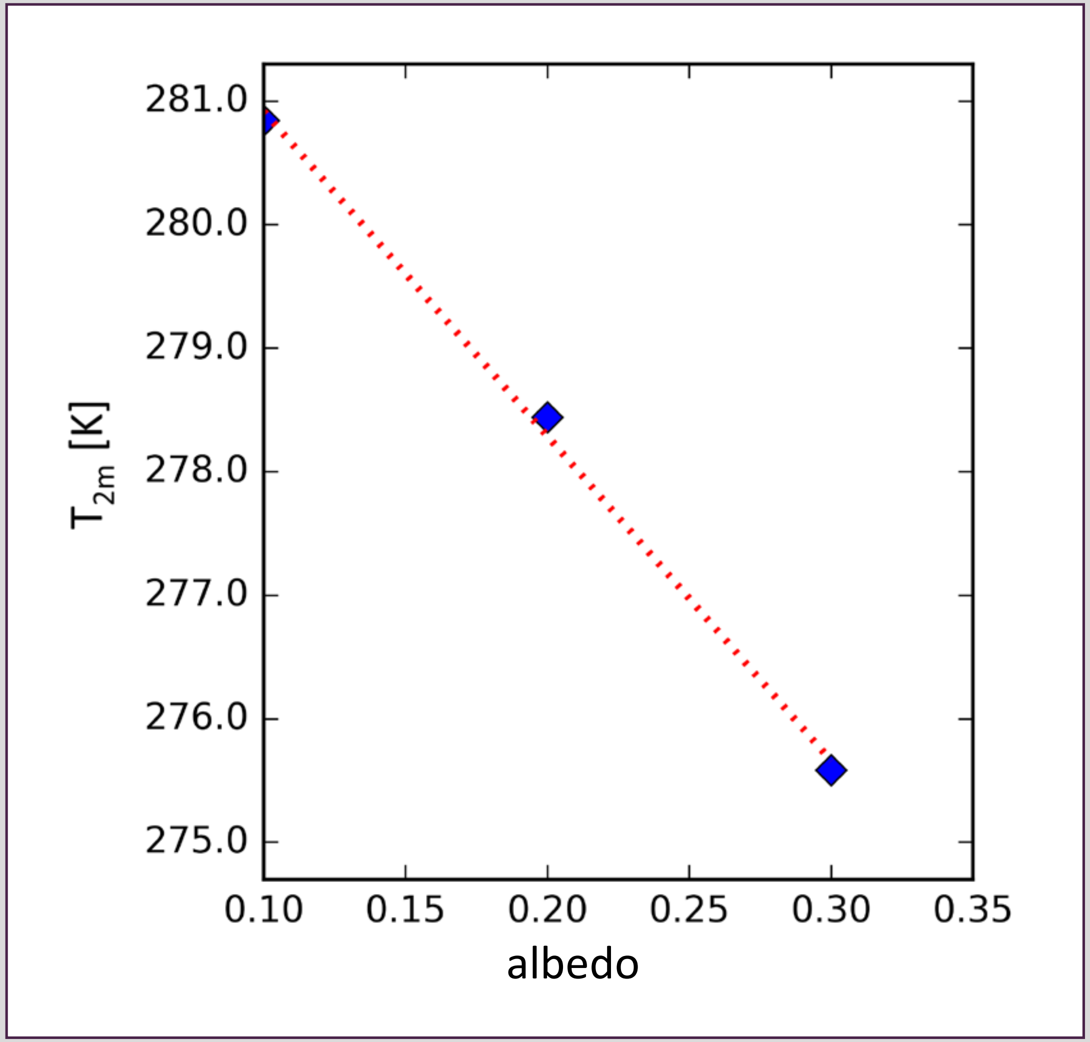
Analysis approach: sensitivity of atmosphere to a change on land

∂ atm ∂ lnd

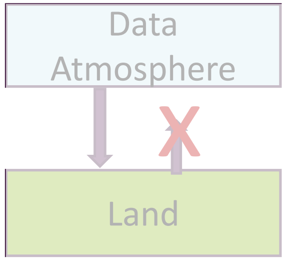


$$\frac{\partial \text{ atm}}{\partial \text{lnd}} = \frac{\partial\, T_{2m}}{\partial\, 0.1\alpha} = 2.6\,\frac{[K]}{[0.1\alpha]}$$

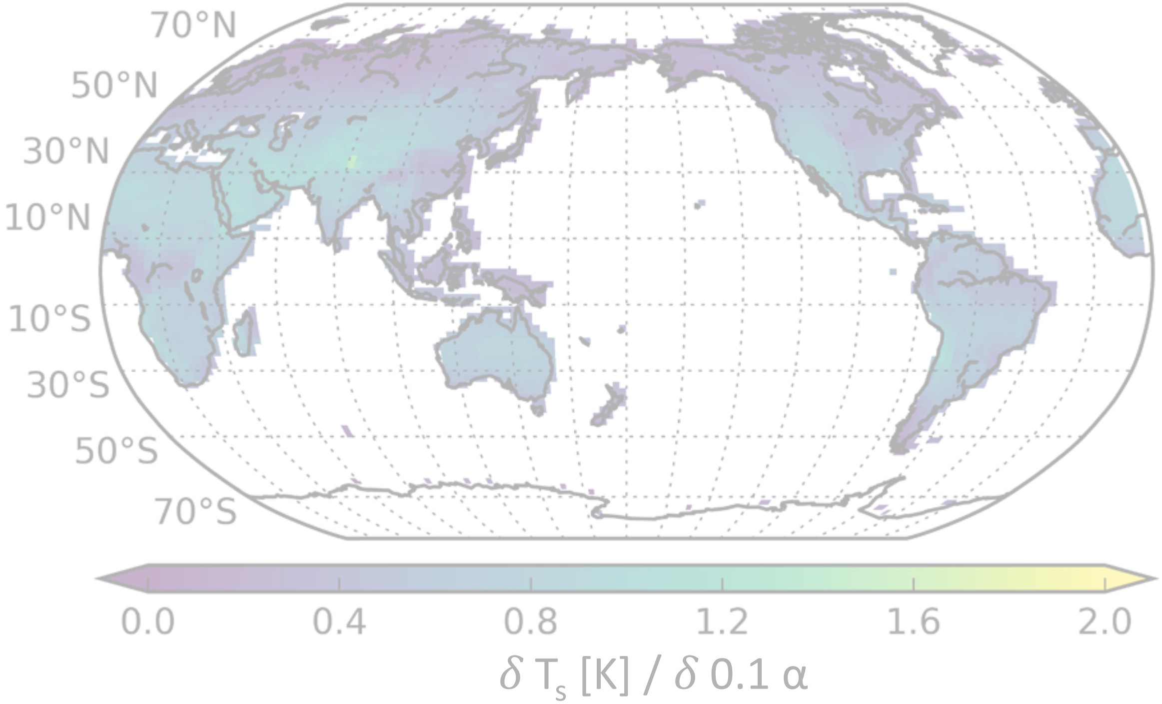
Get 2.6 K warming
for every 10% darker
the surface becomes



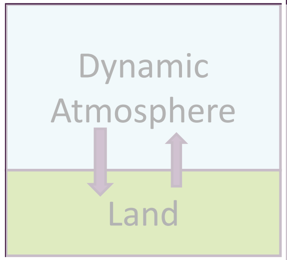
Tropics have small response in T_s, but big change in evaporation

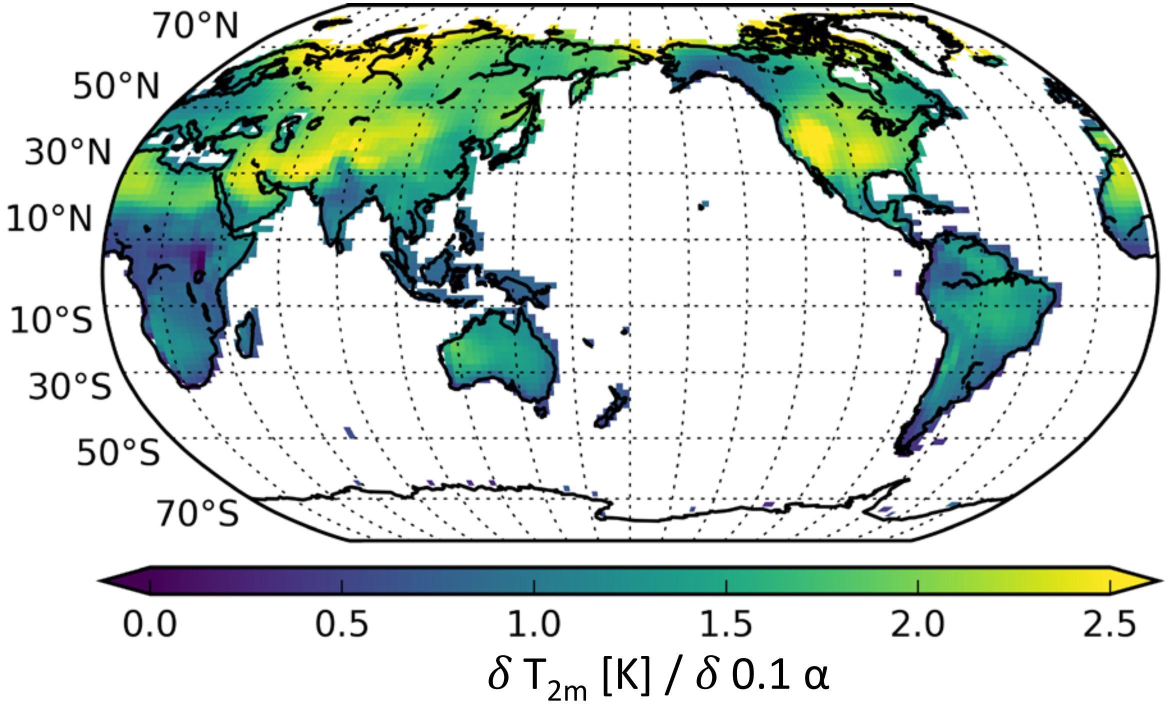


Land only ("Forcing")



Coupled (Feedbacks + Forcing)

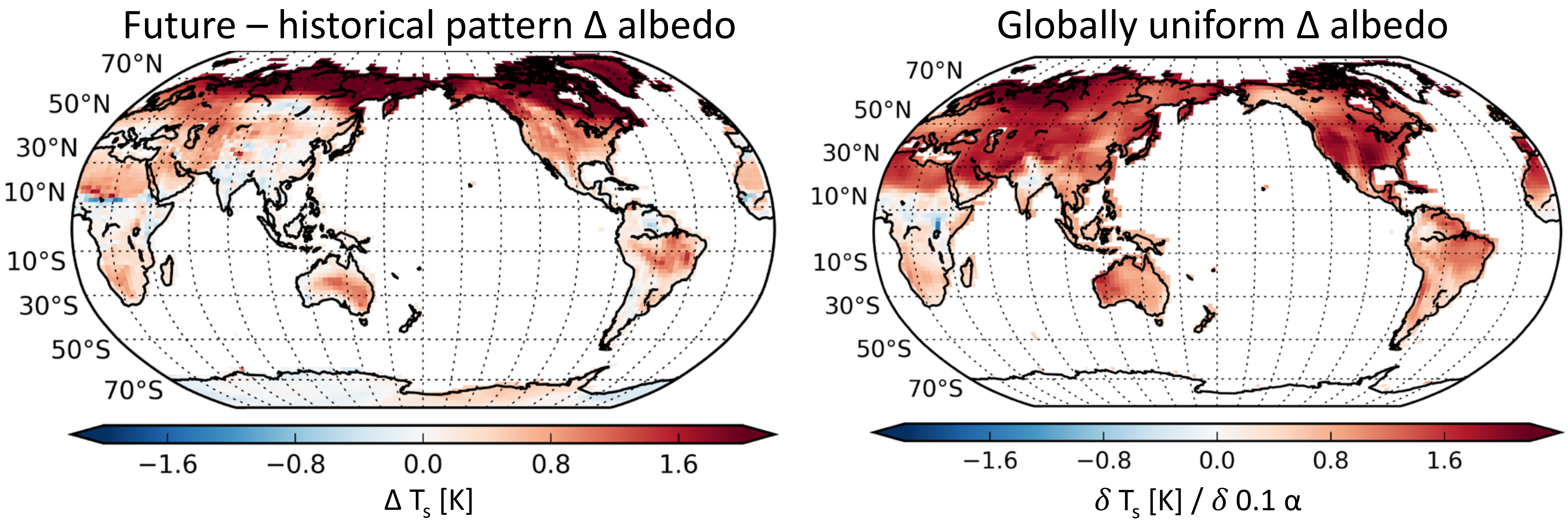




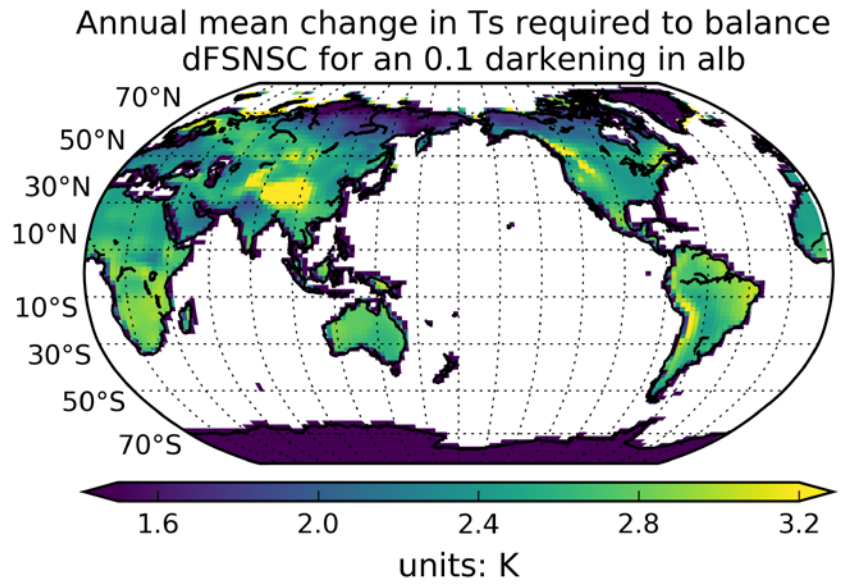
Albedo

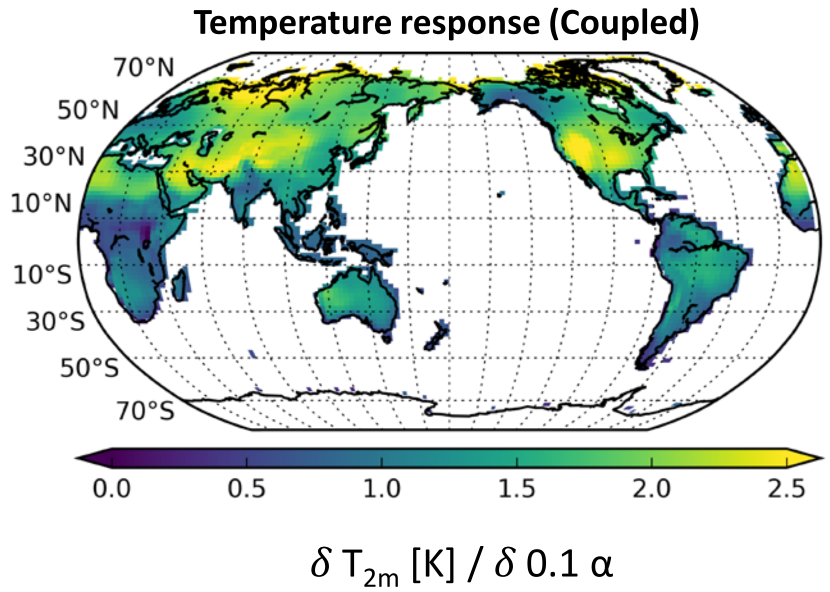
Isolate the warming signal coming from changes in the atmosphere:

Warming due to atmospheric feedbacks

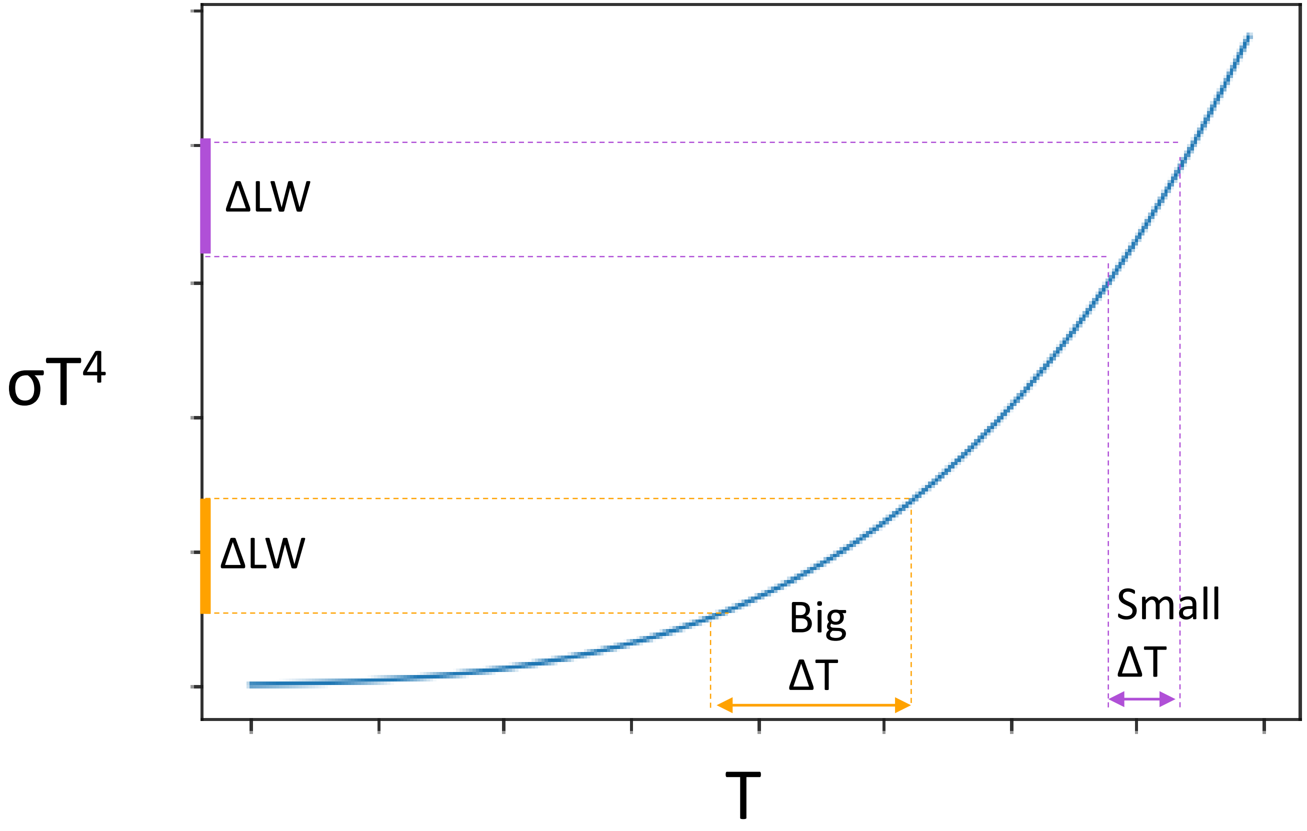


Large-scale precipitation shifts. How much is local (e.g. Amazon) vs circulation-driven (e.g. ITCZ)?

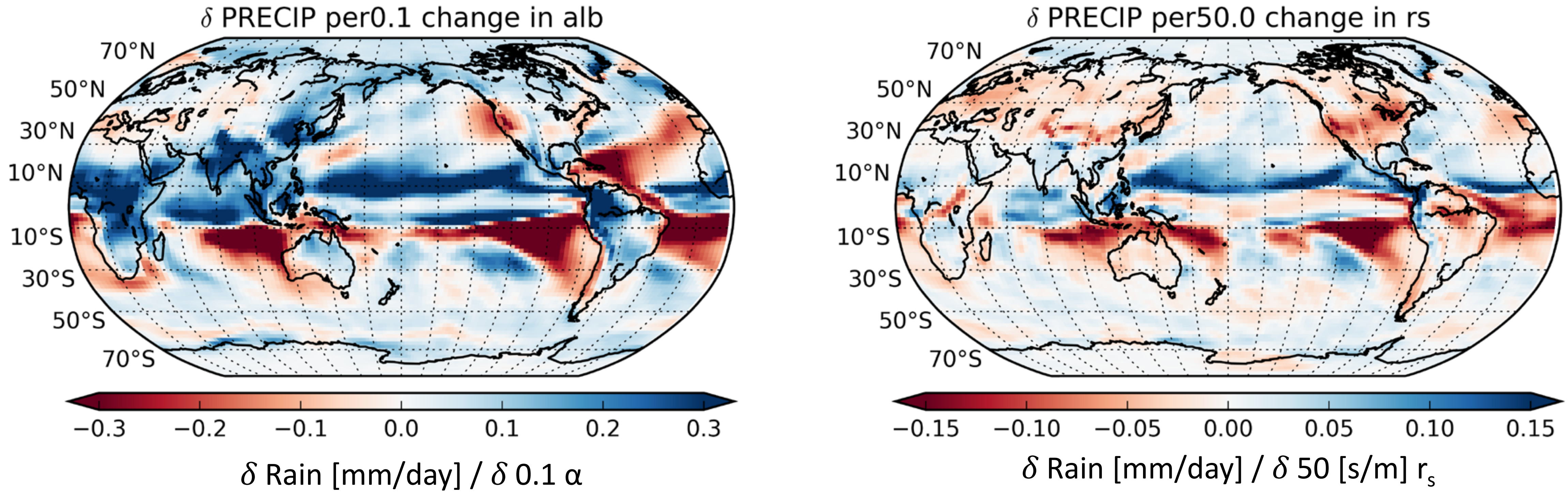




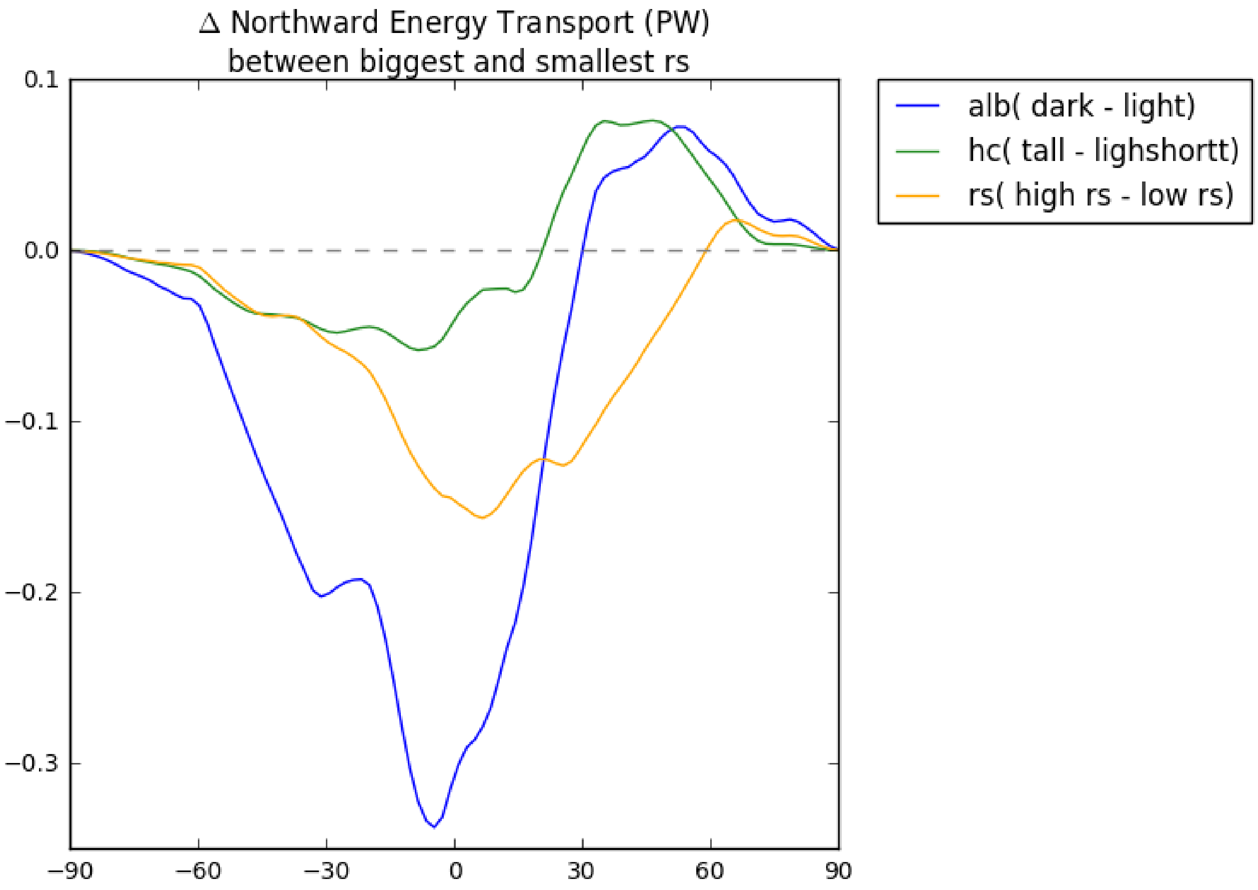
$LW_{up} = \sigma T^4$

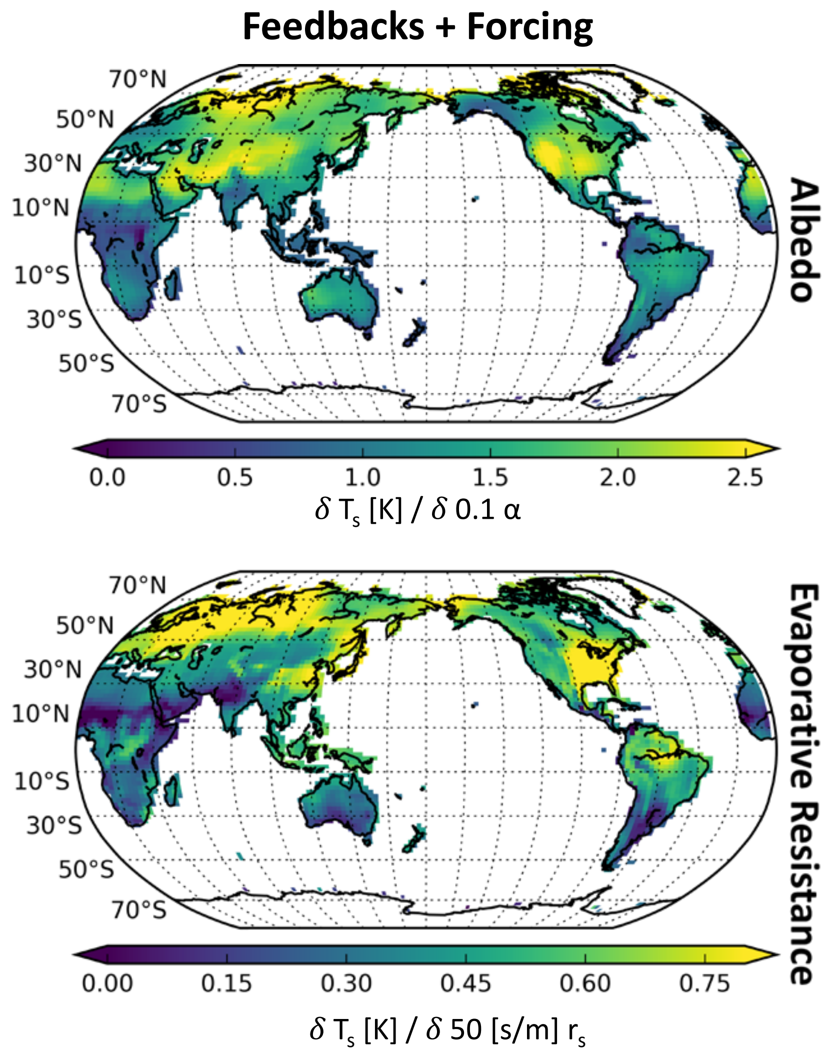


Large-scale precipitation shifts. How much is local (e.g. Amazon) vs circulation-driven (e.g. ITCZ)?



Albedo sensitivity in Arctic must be remote – no sun. But, more energy is bring transported north.





High lats DJF: covered with snow, and no sun in winter = warming must be coming from albedo change everywhere else