Using idealized land modeling to pick apart land-atmosphere interactions

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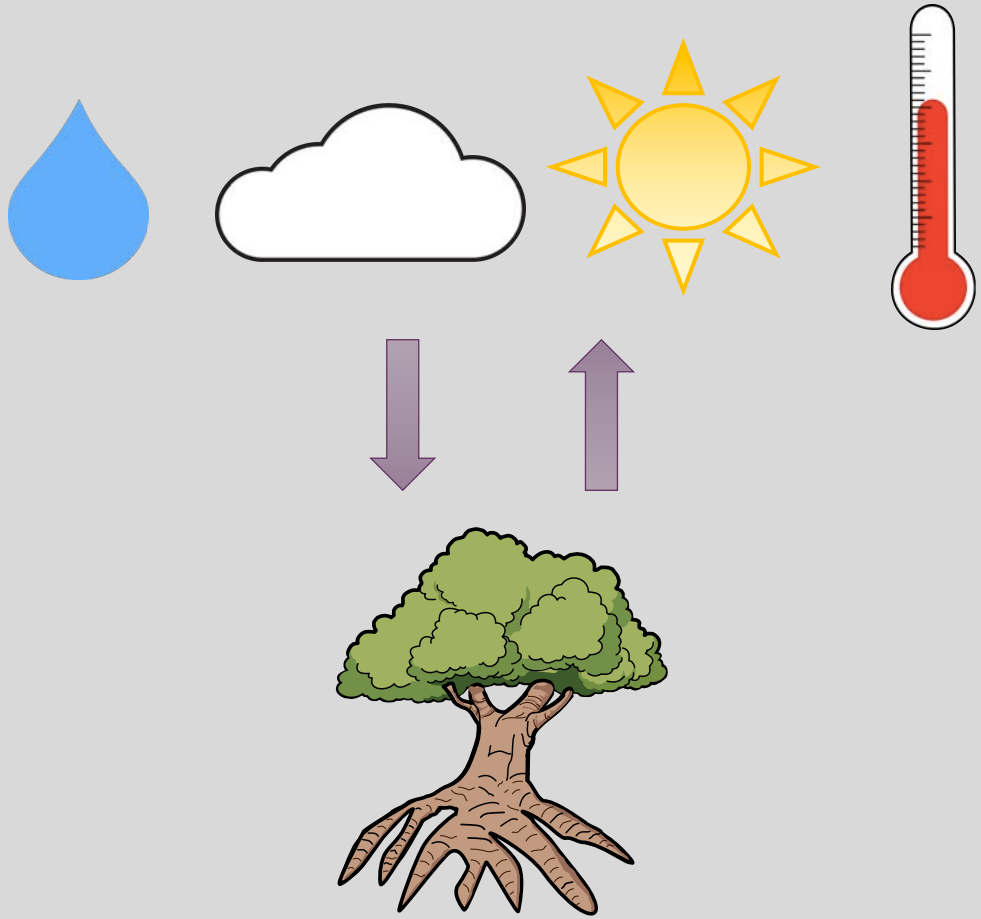
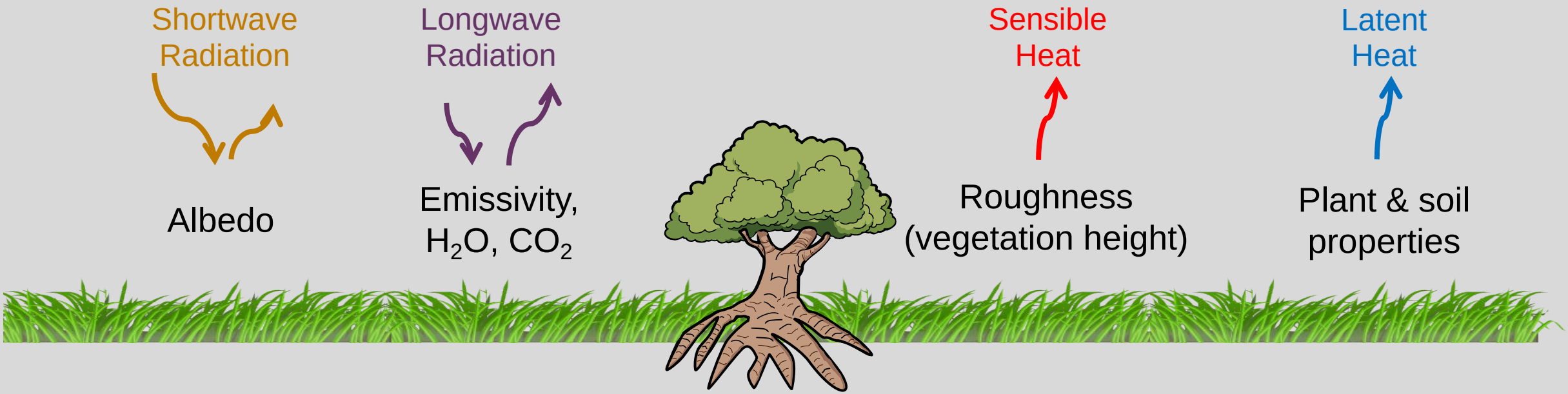
Where does the atmosphere care about changes in vegetation? (And what about the plants does it actually care about?)

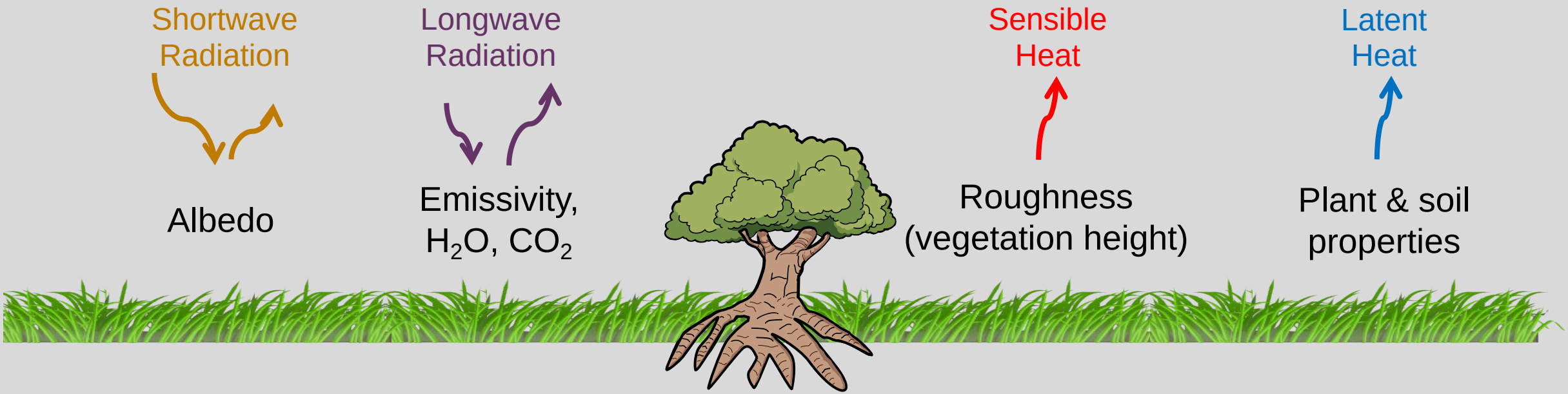


Changes in **surface properties** impact different **surface energy fluxes**



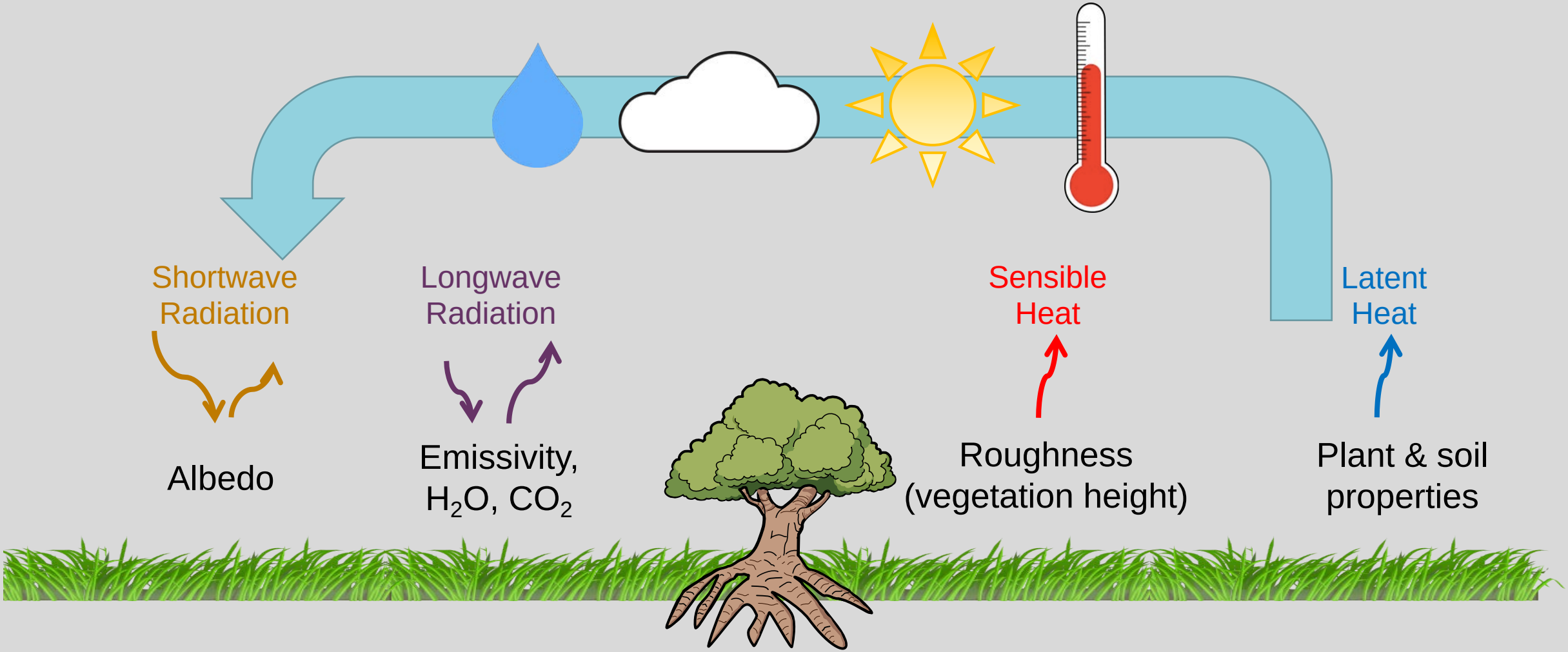
These changes in **surface fluxes** modify surface climate **directly**

(e.g. changes in surface temperature or turbulent fluxes)

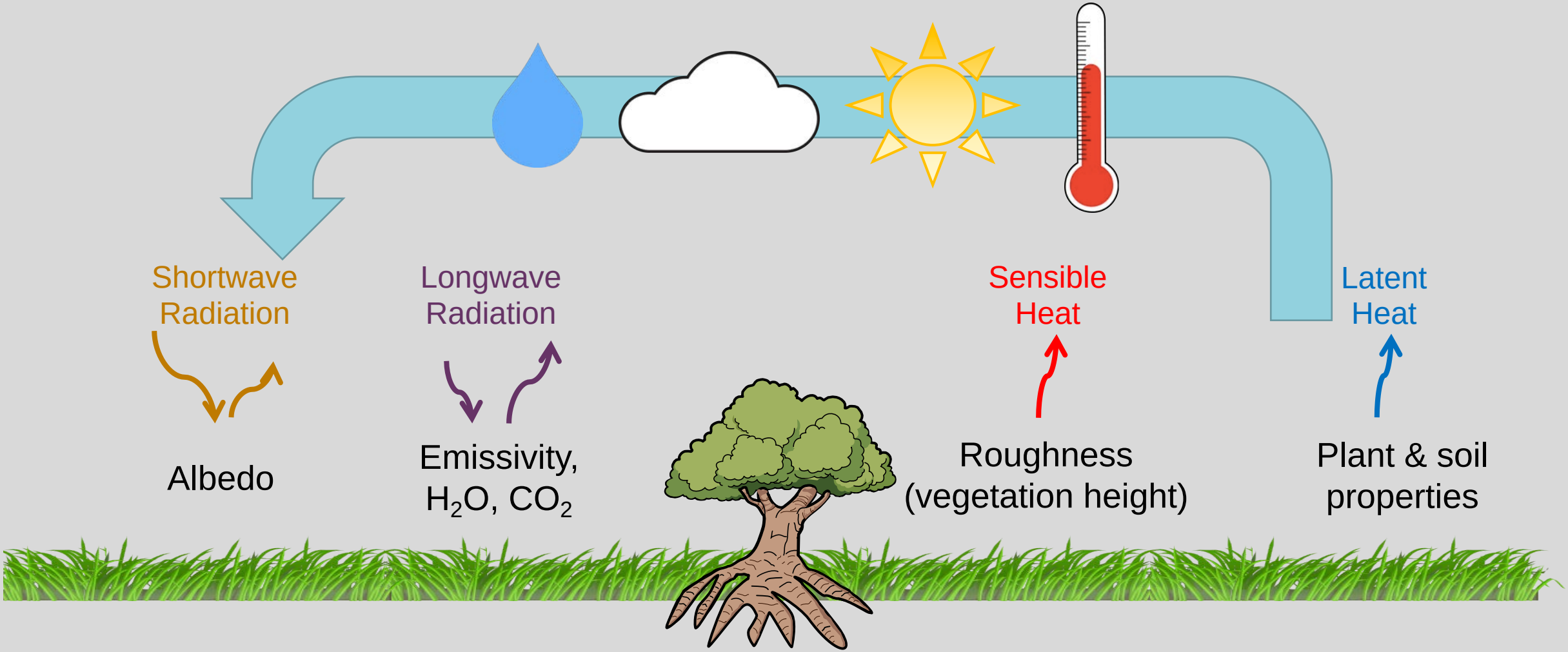


These changes in **surface fluxes** modify surface climate **directly** and through **atmospheric feedbacks**

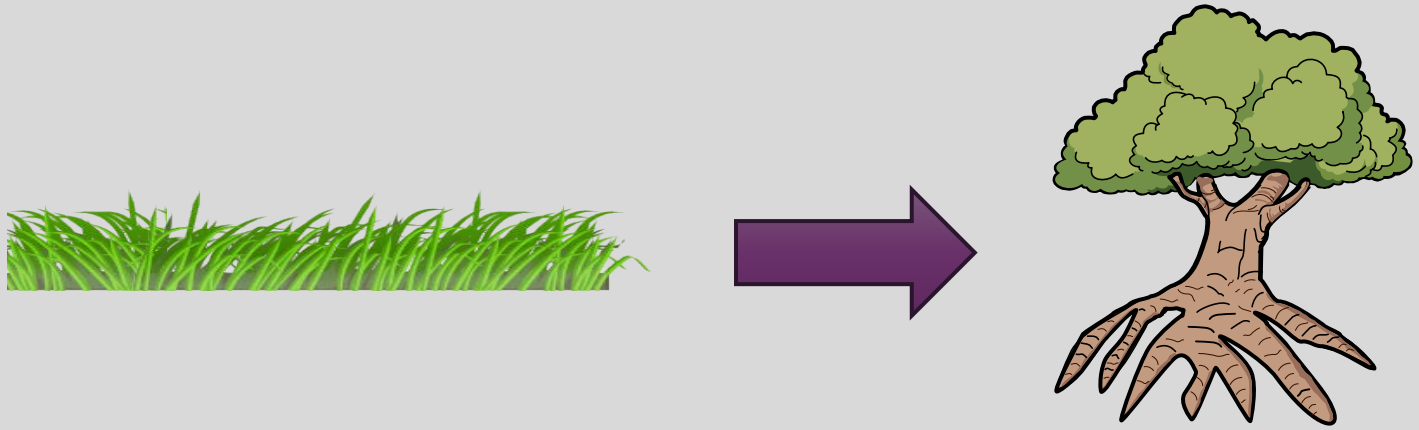
(e.g. through modifying rain, clouds, sun, air T, humidity, etc.)



How do individual land surface properties (albedo, evaporative resistance, etc) influence the climate that the land surface experiences?



In a typical modern Earth System Model, changing vegetation type means changing many things about the land surface at the same time



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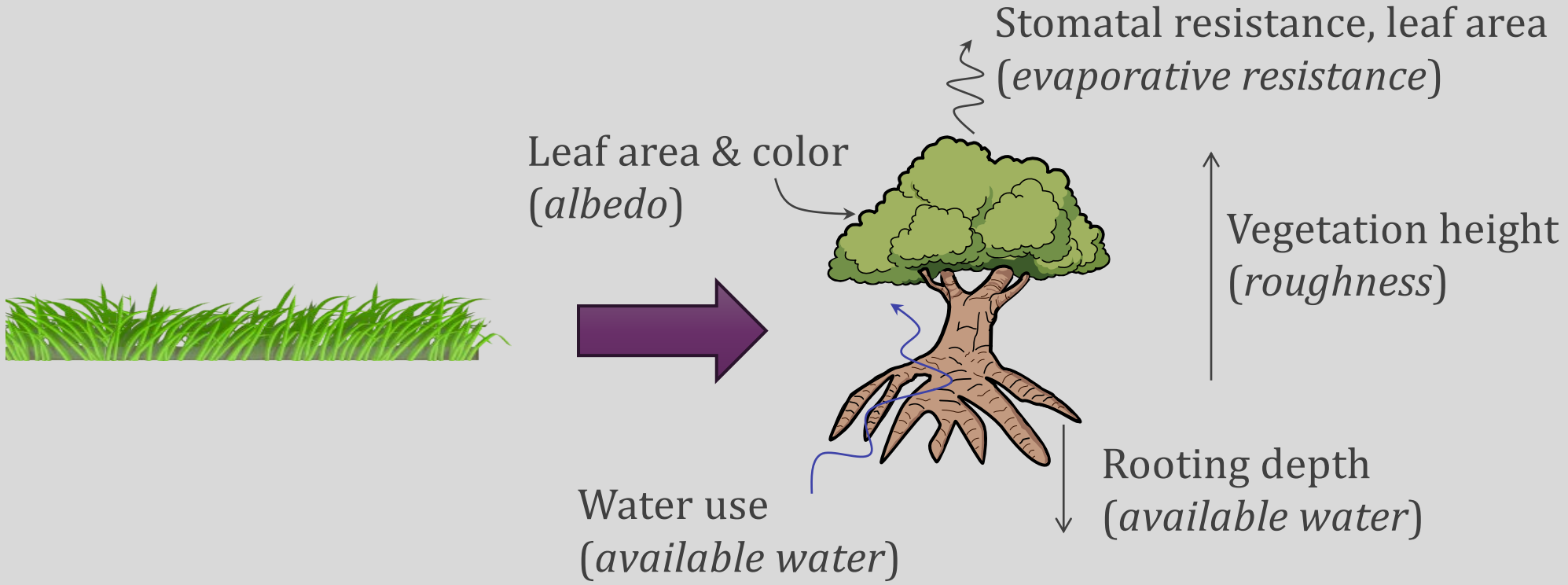

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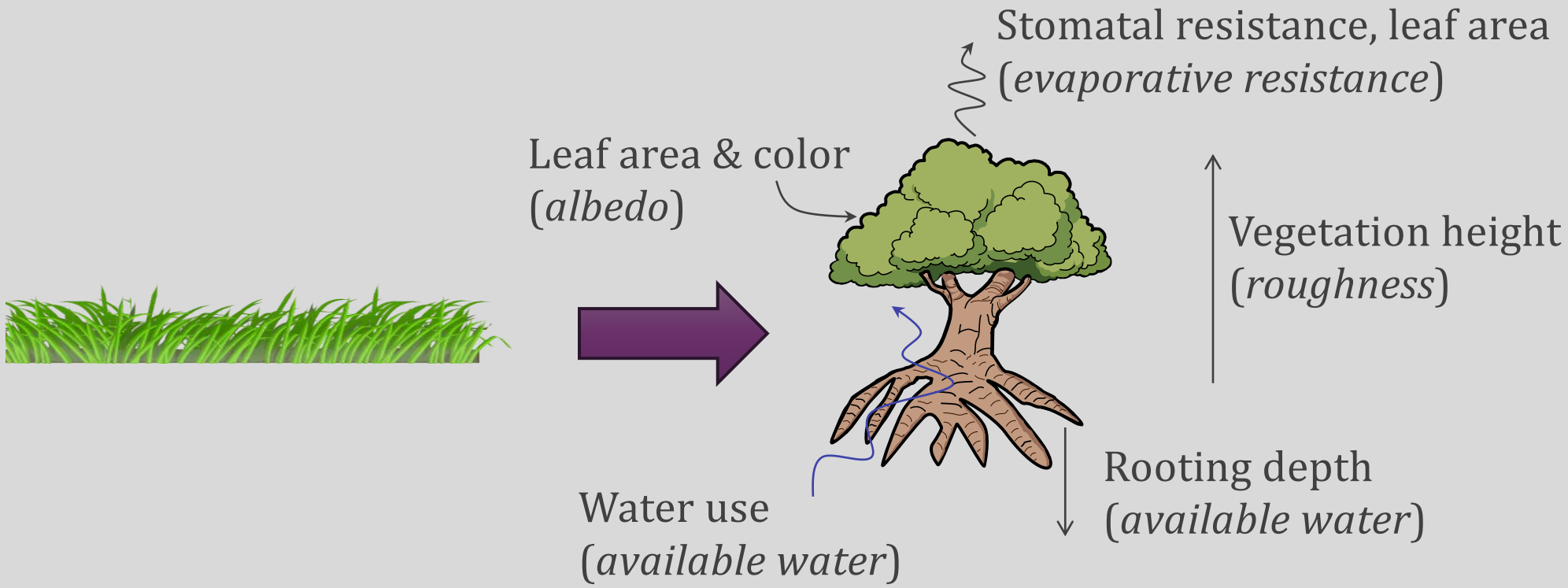
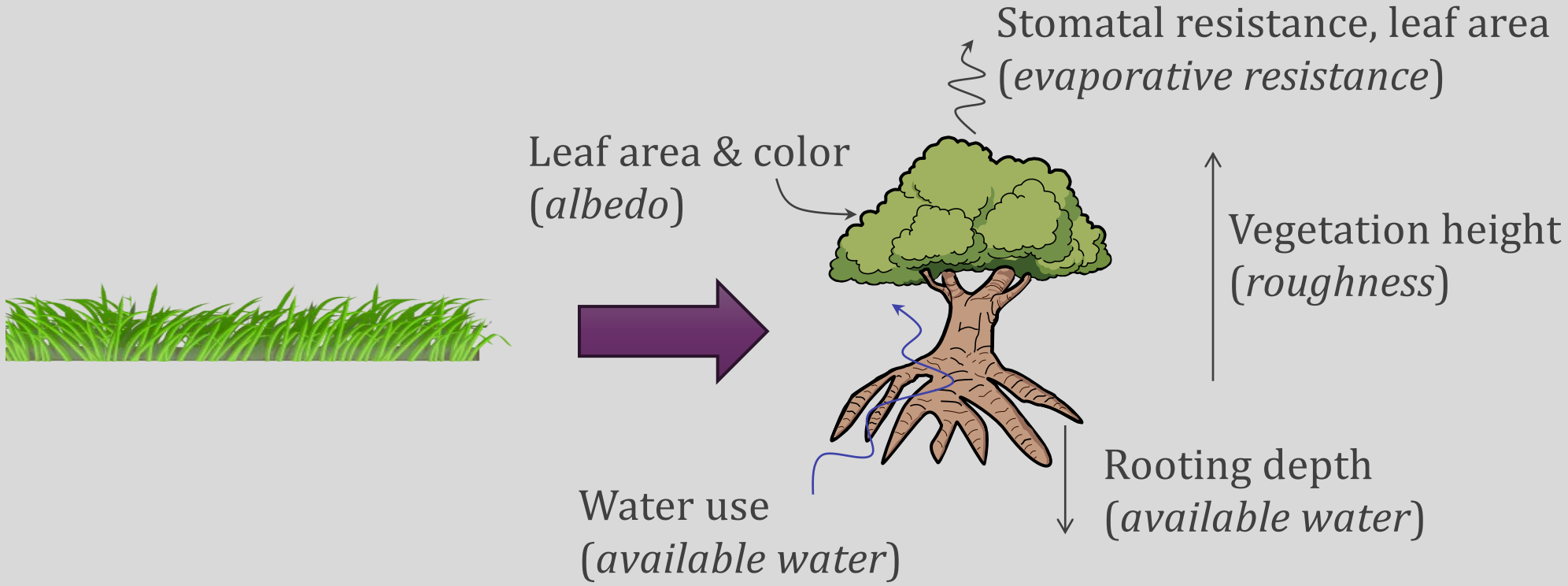
- Don’t know which particular change in the land surface the atmosphere is responding to

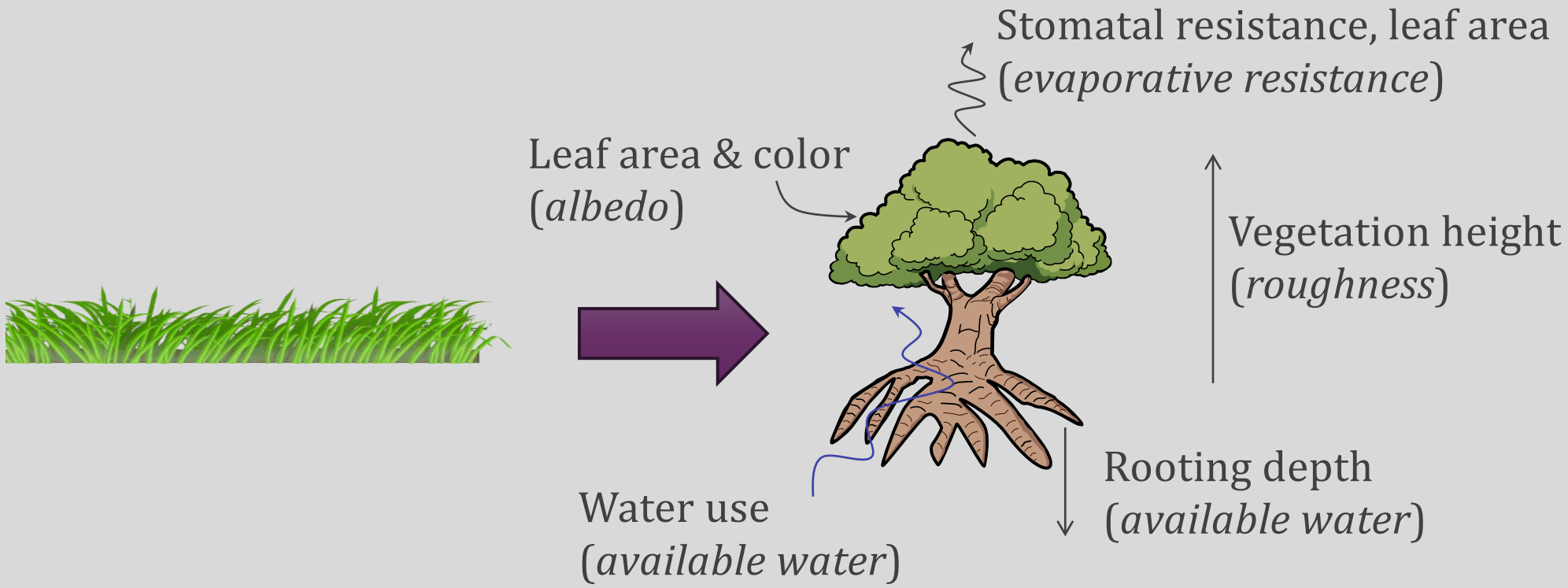


In a typical modern Earth System Model, changing vegetation type means changing many things about the land surface at the same time

- 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**

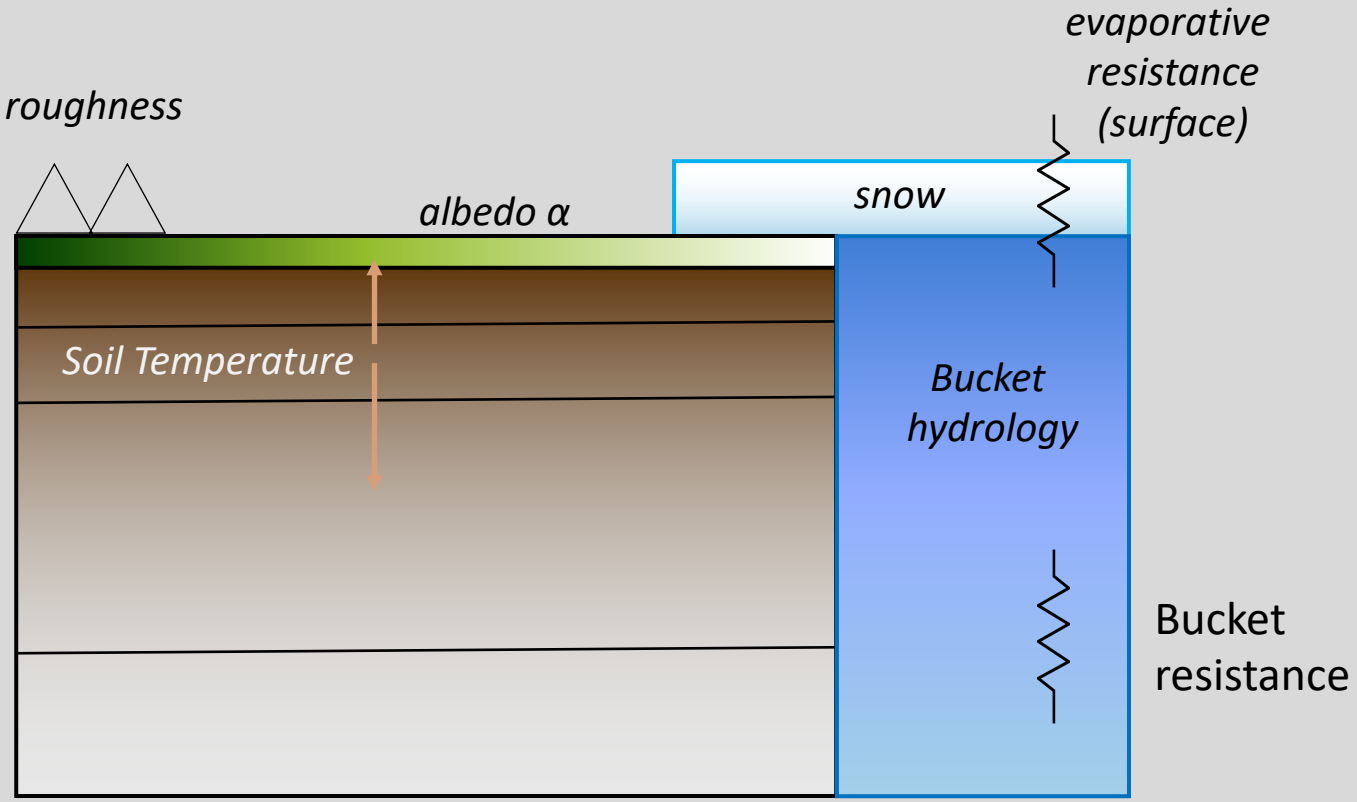


Rather than considering all the effects of a change in vegetation at once, use an idealized land model to isolate changes to individual properties of the land surface



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



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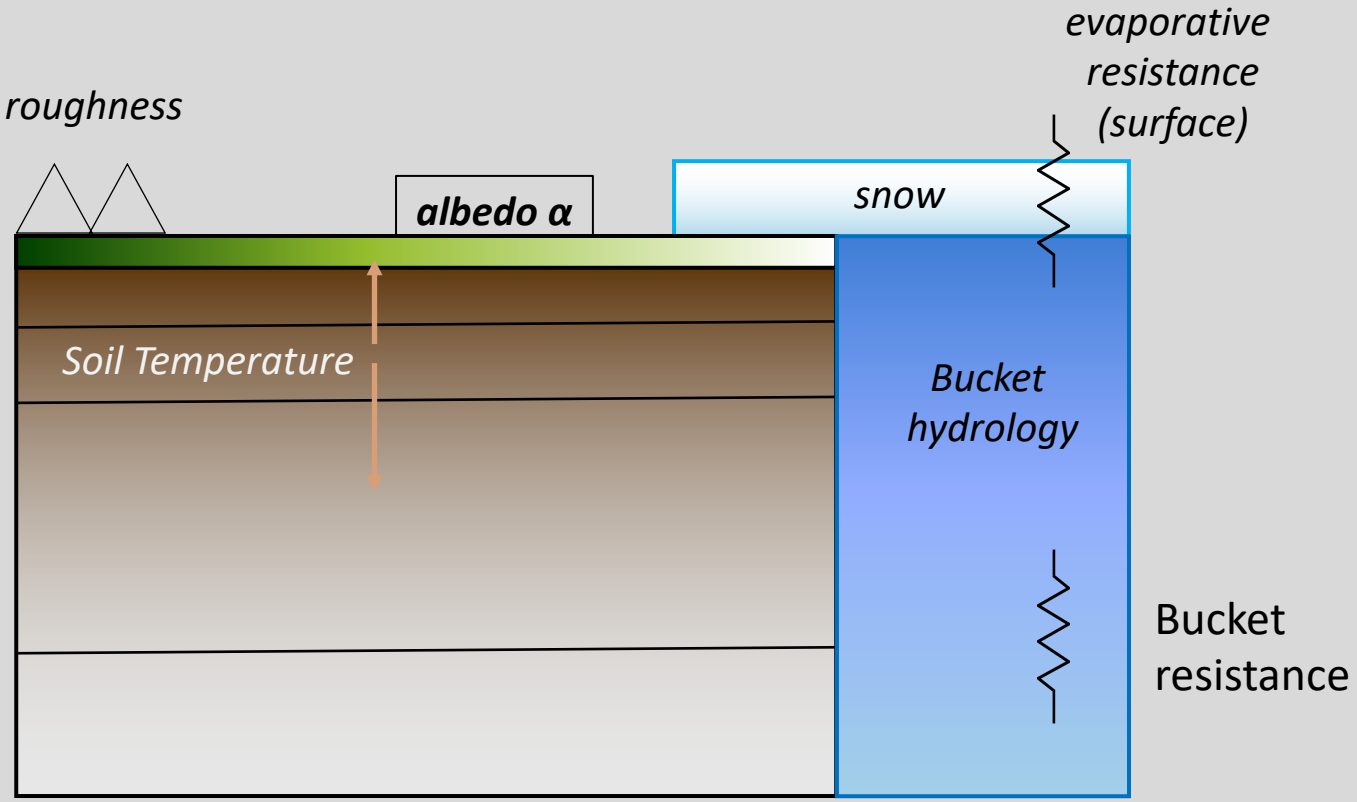
e.g. change **albedo** and know the rest of the climate system is **only** responding to that change in albedo



Idealized example: how do uniform changes in albedo vs. evaporative resistance influence surface temperature? (In a coupled model)

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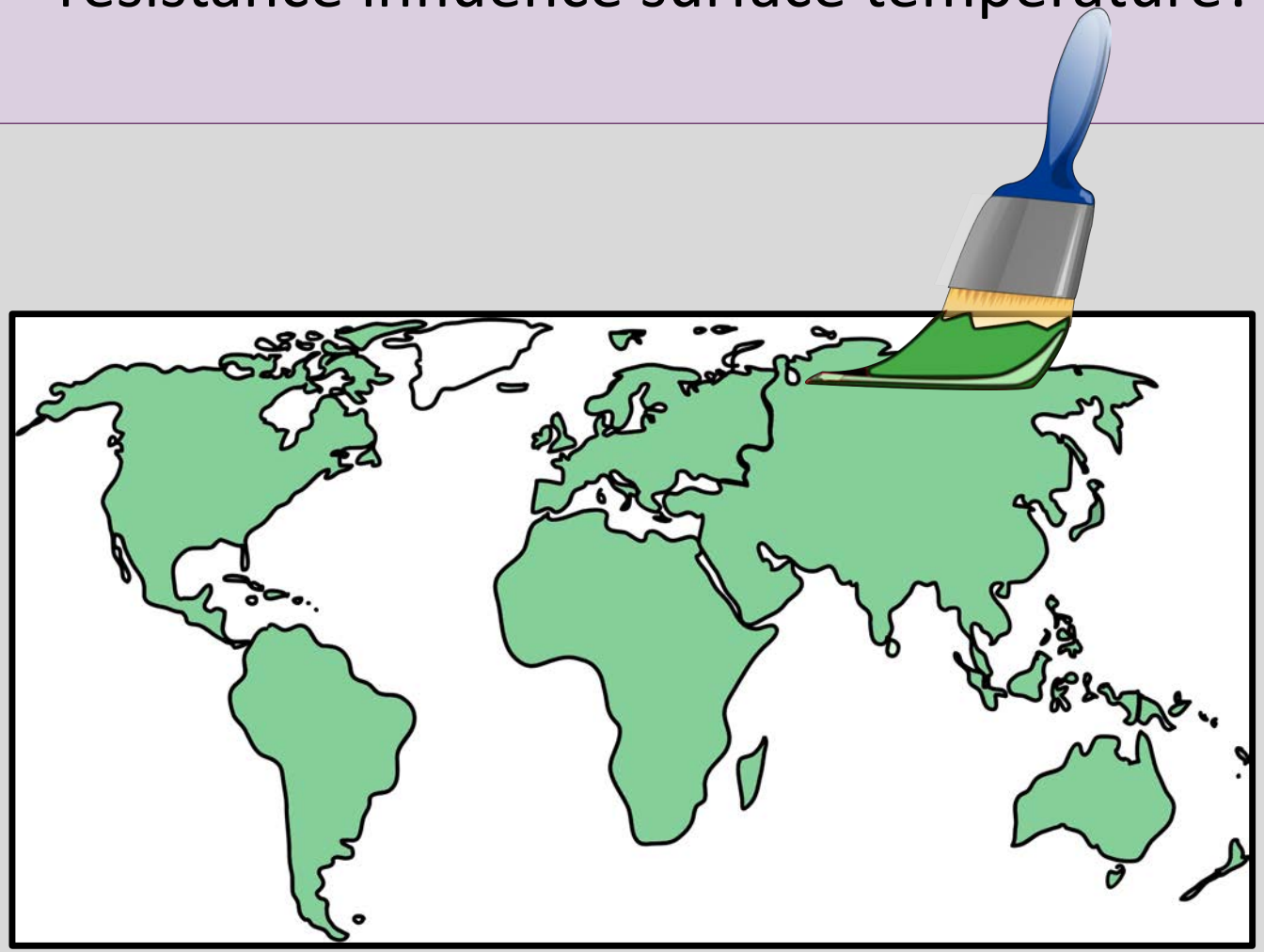

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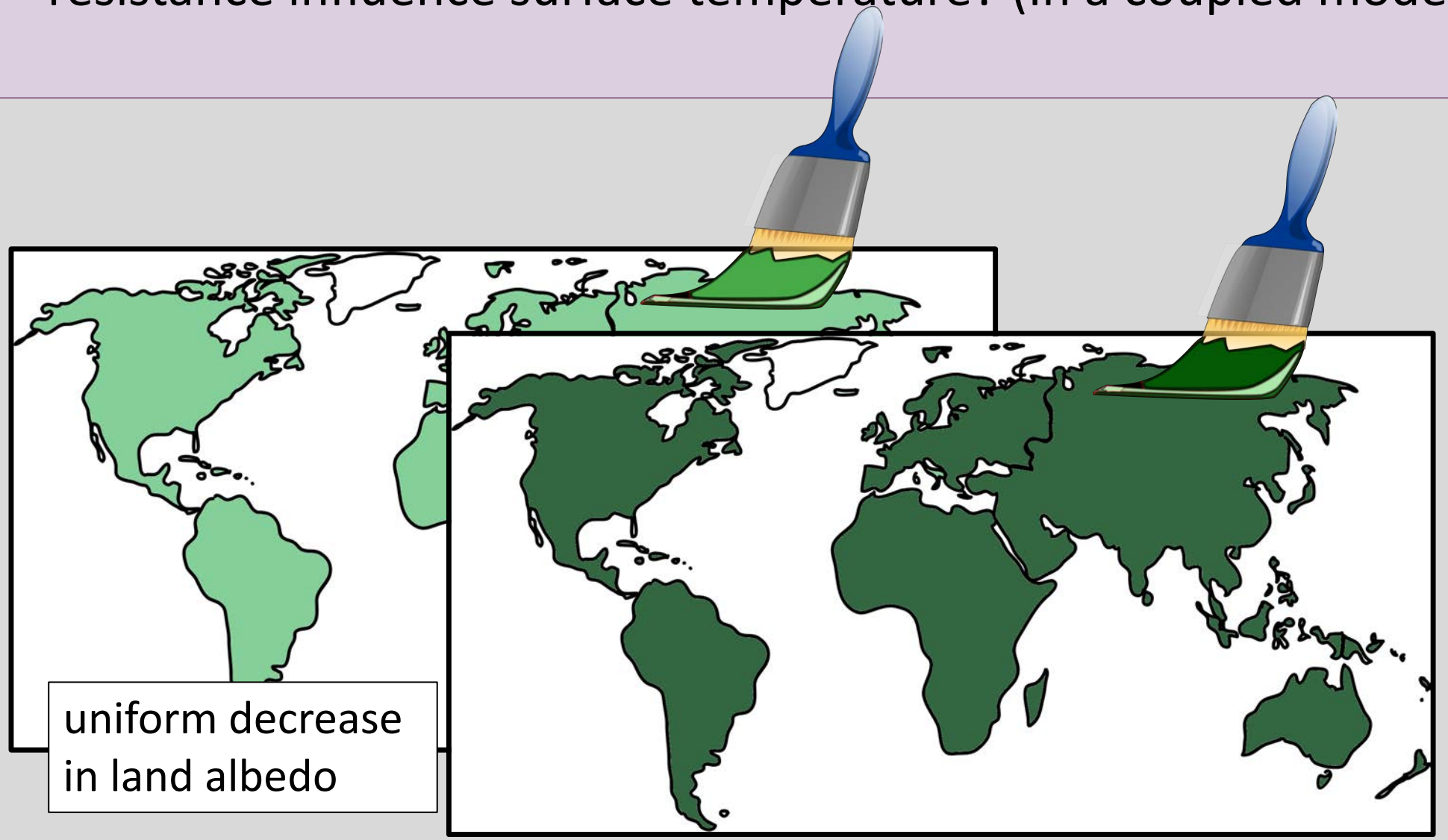
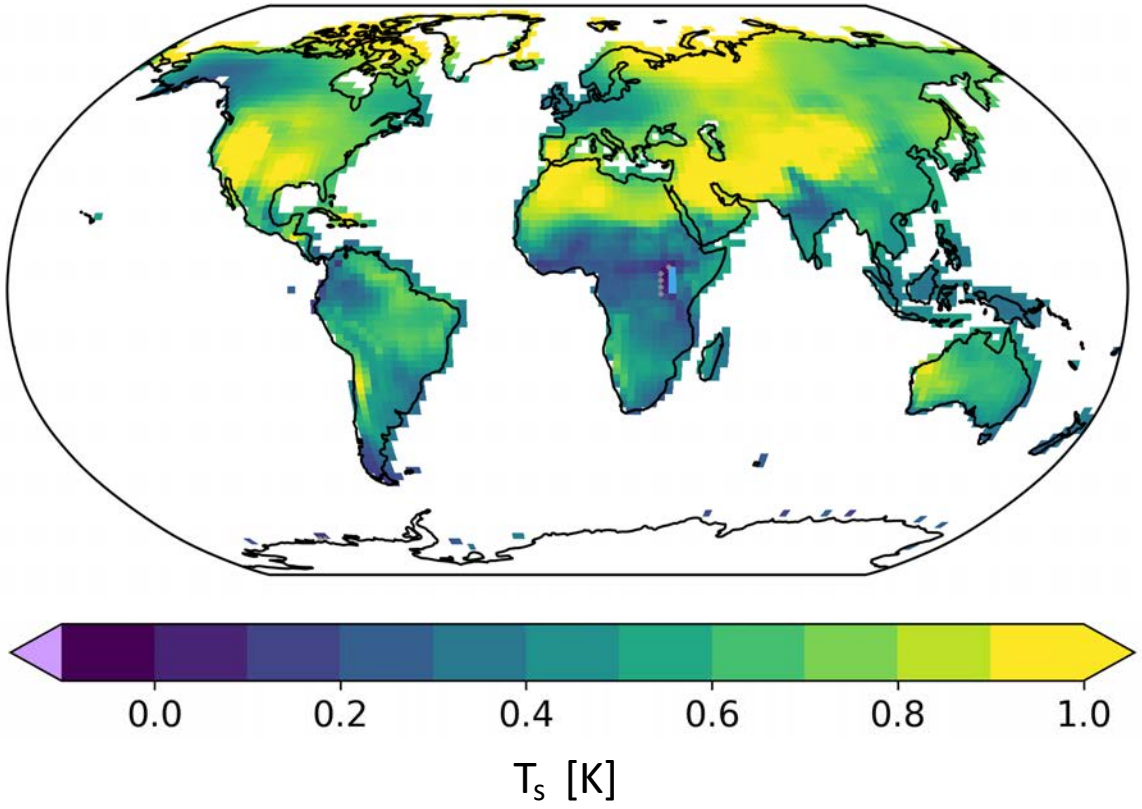


Idealized example: uniform decrease in land albedo

Change in **temperature** per **0.04 darkening of albedo**



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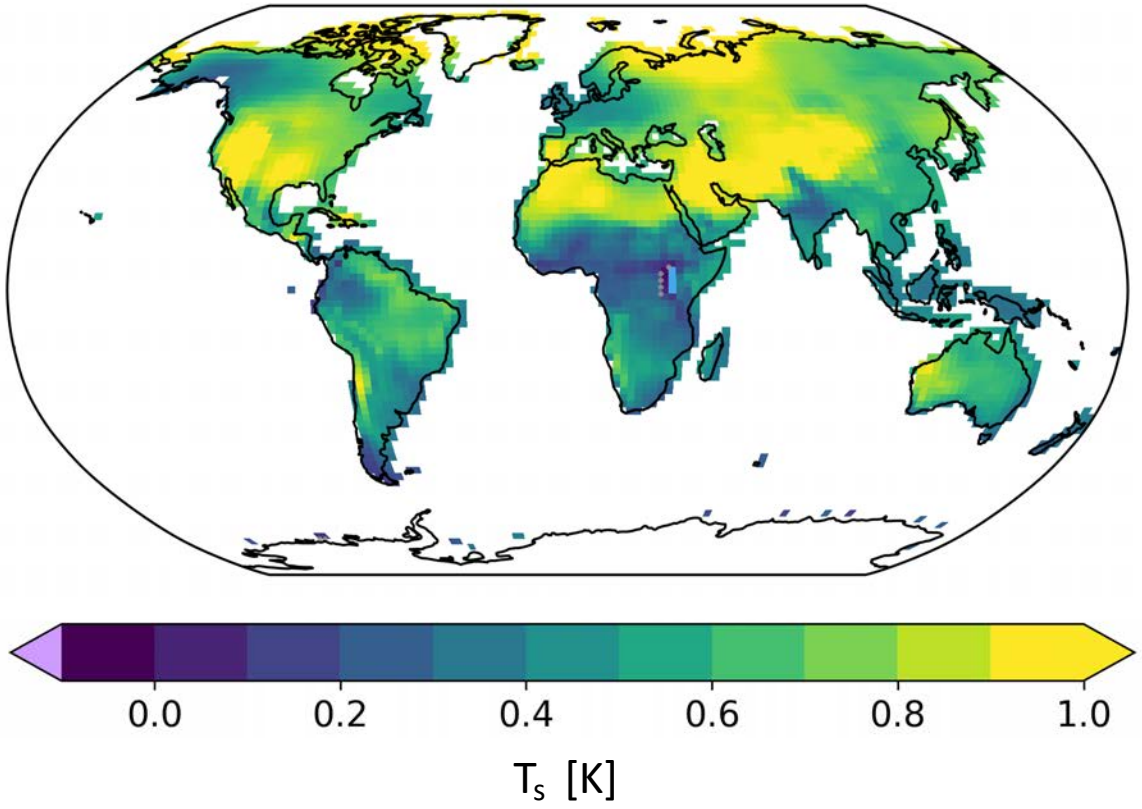
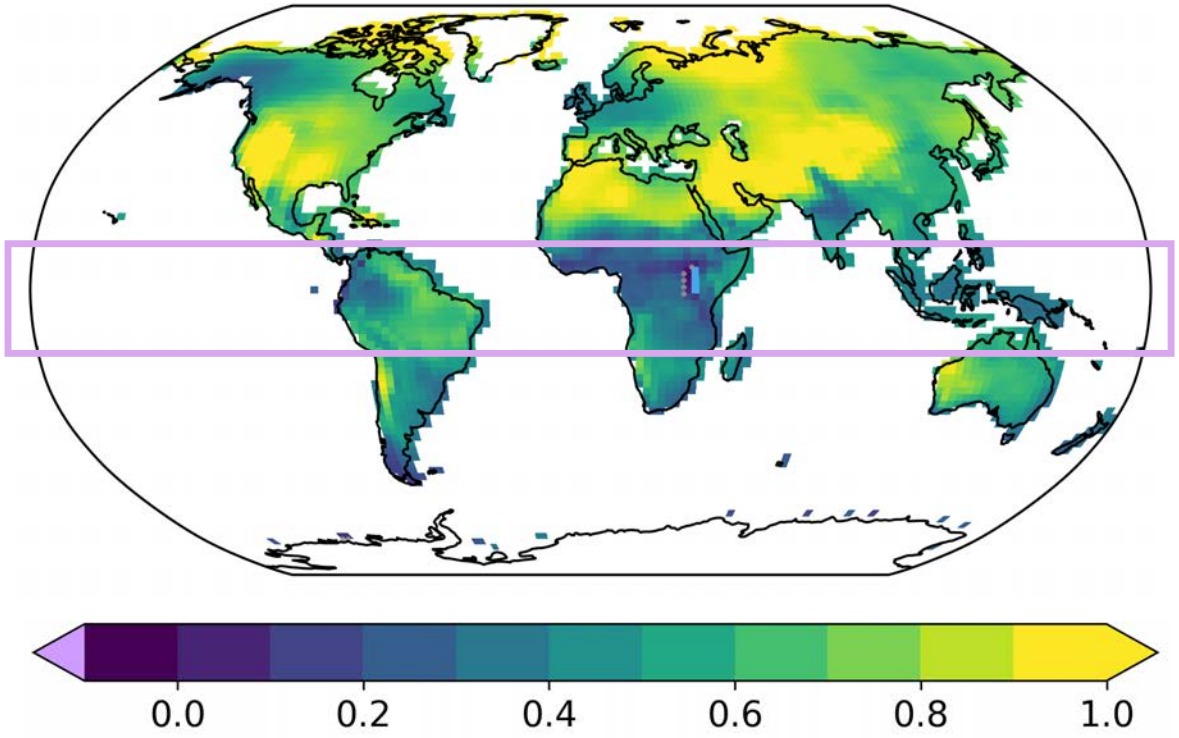


Darker land = more absorbed sun

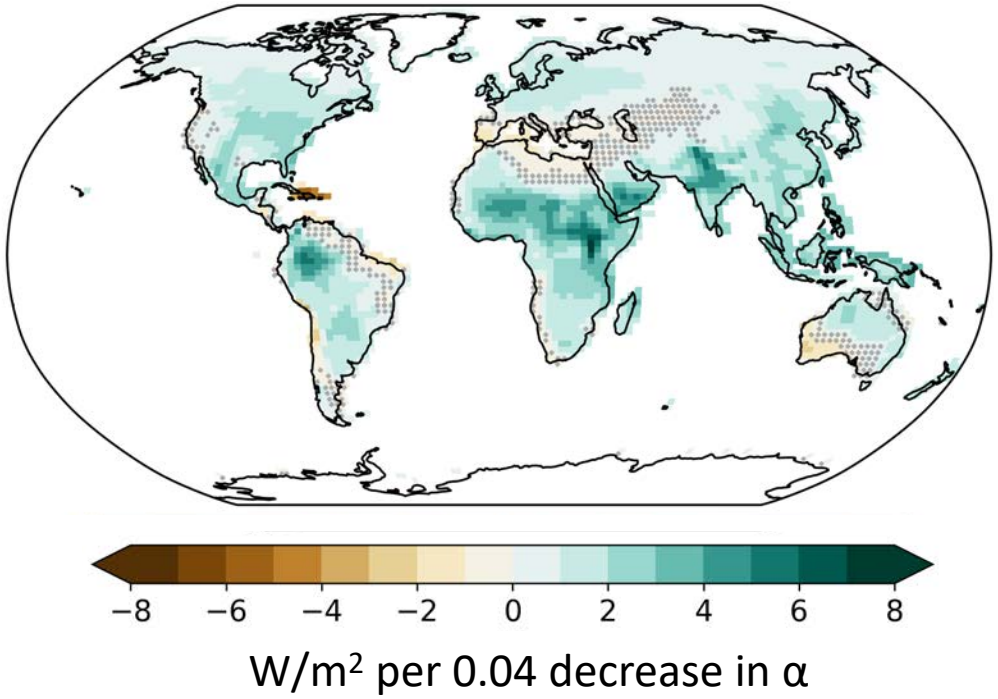
How the surface energy budget deals with this extra energy varies by location

Tropics: small change in temperature, big change in evaporation

Change in **temperature** per **0.04 darkening of albedo**

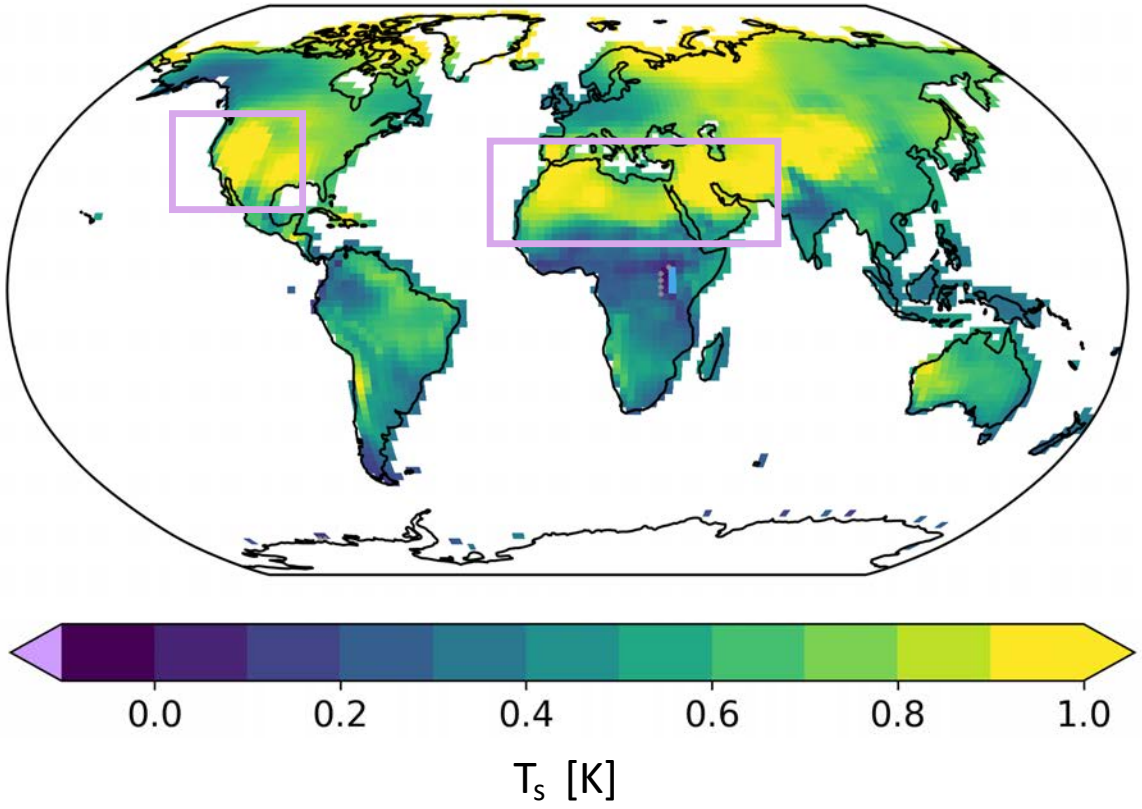


Δ Latent heat flux



Deserts: big change in temperature (not much water to evaporate)

Change in **temperature** per **0.04 darkening of albedo**



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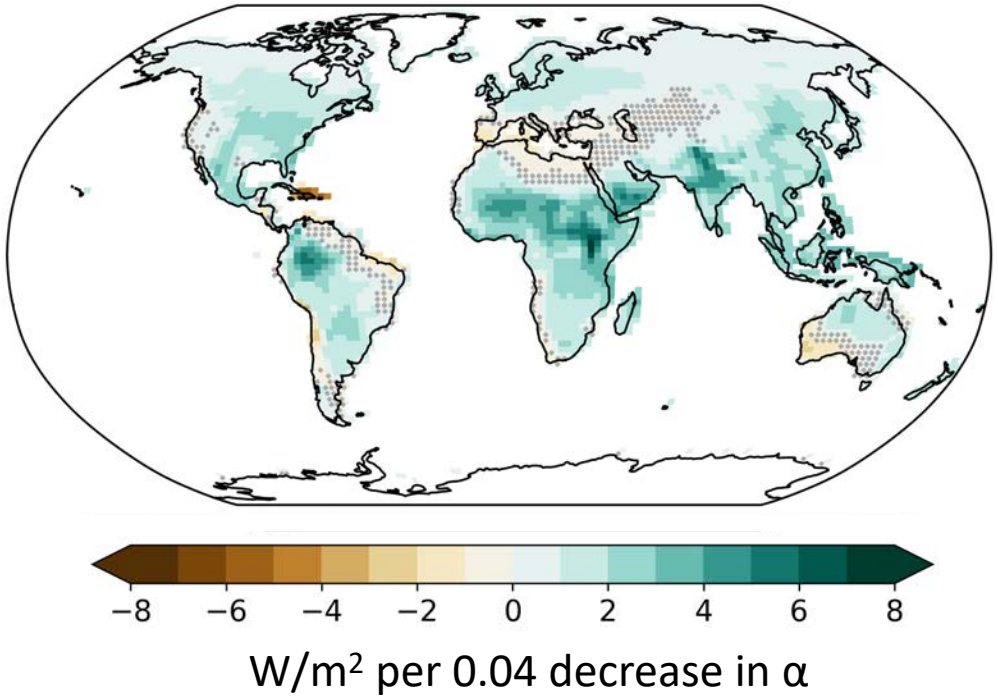

Changing plants changes lots of things, not just albedo

Albedo

Directly changes the **total** amount of energy absorbed by the land surface.

Evaporative resistance

Modifies **partitioning** between latent and sensible heat fluxes

Idealized example: uniform increase in land **evaporative resistance**

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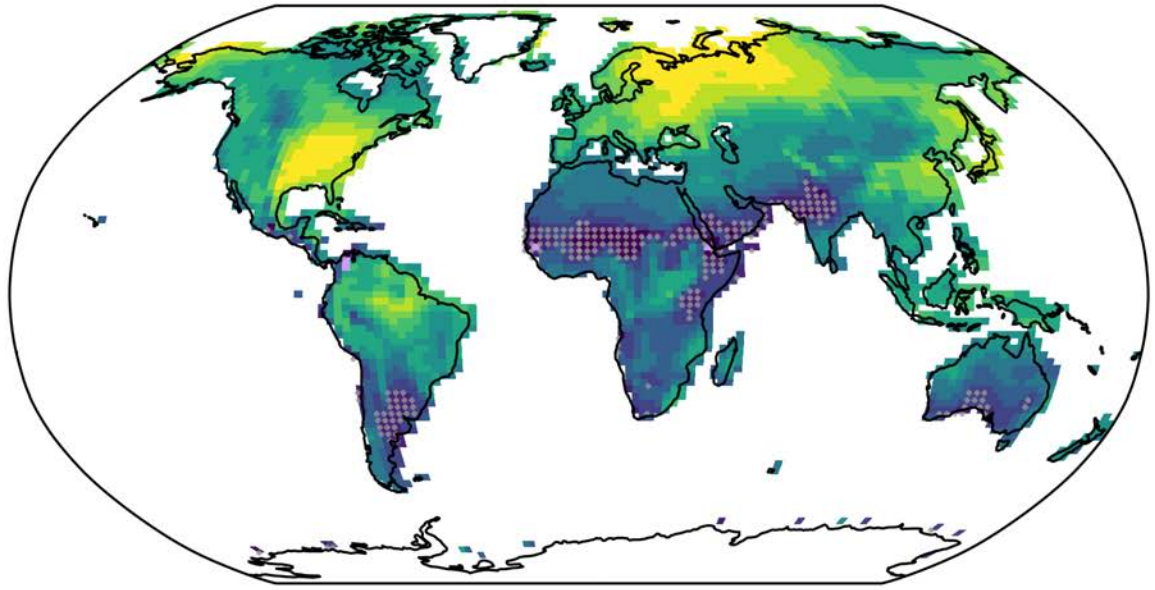
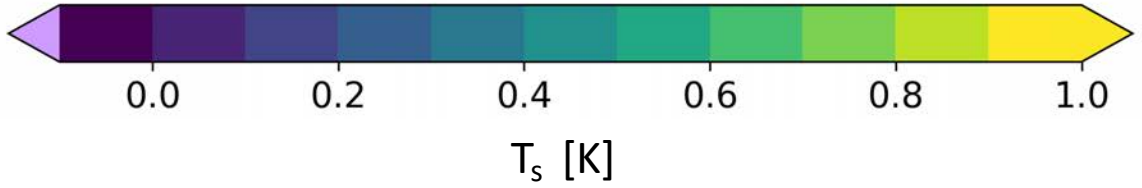
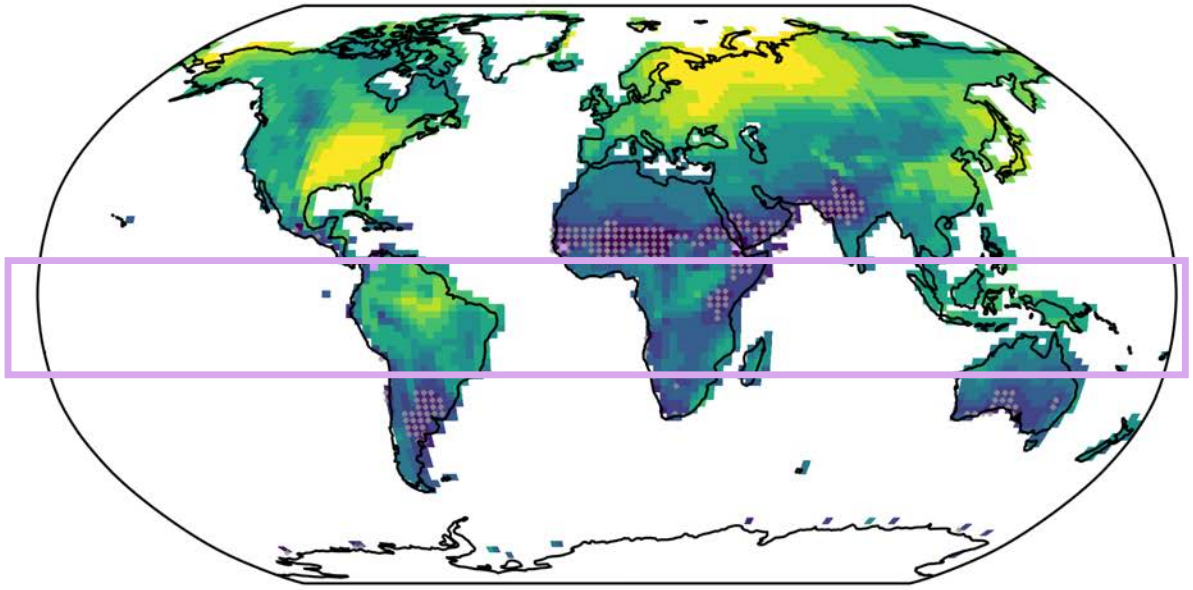
Change in **temperature** [K] per 50 s/m increase in r_s

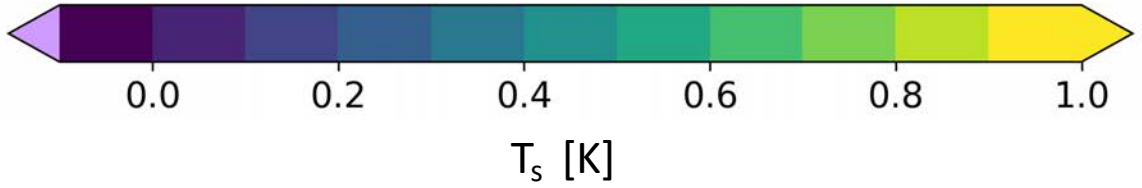




Surface temperatures change in places where water plays a big role in the surface energy budget

Change in **temperature** [K] per 50 s/m increase in r_s





Surface temperatures **don't** change in places where there isn't any water (changing evaporative resistance over a desert doesn't matter much)

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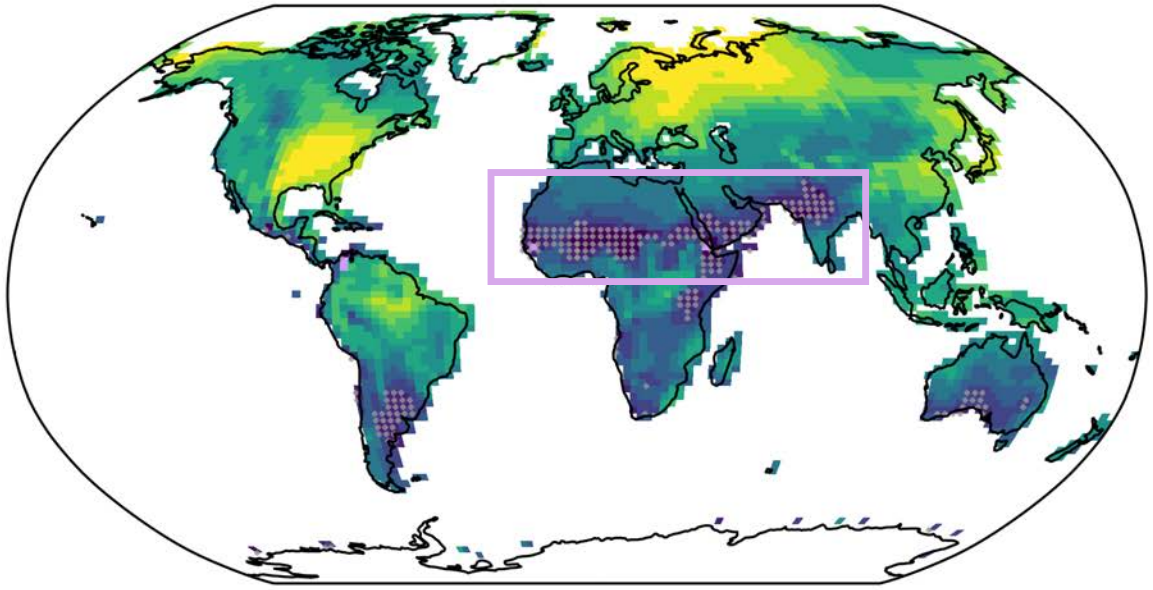
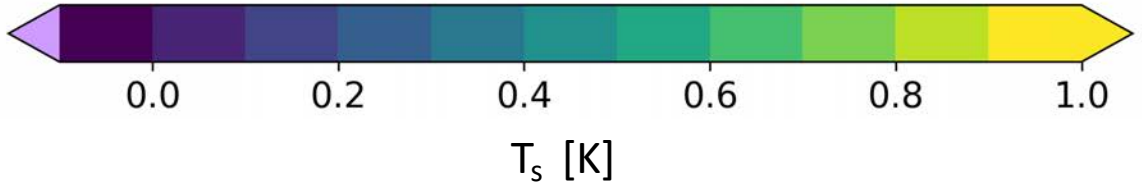
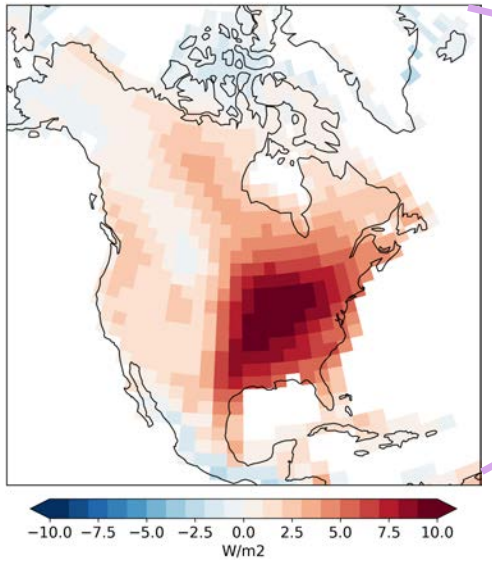




Surface temperatures change in places where water plays a big role in the surface energy budget **and** where clouds respond to changes in land evaporation!

↓ evaporation drives ↓ low clouds
= ↑ sun reaching ground



δ SW_{net} / δ 50 [s/m] r_s

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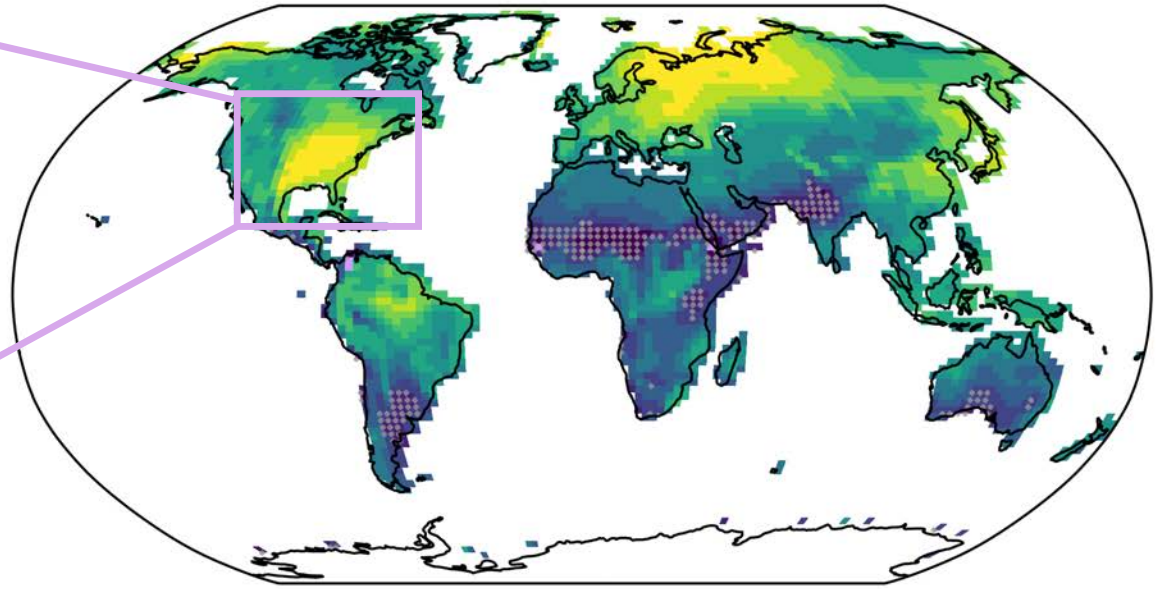
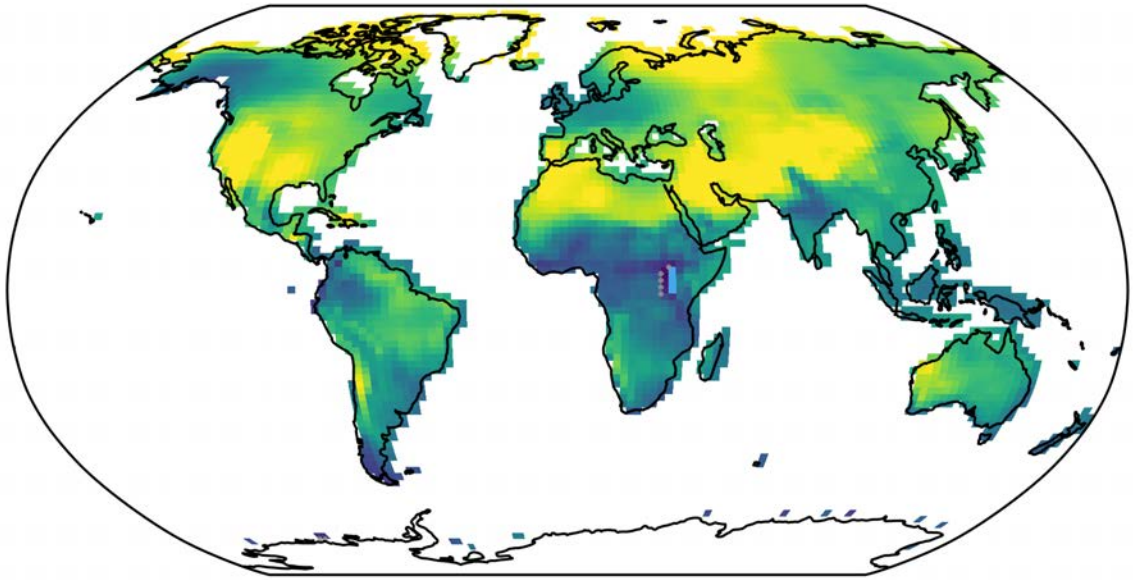


T_s [K]

Albedo and evaporative resistance both change with vegetation, but where they play a big role in surface temperatures is pretty different

Change in **temperature** per **0.04 darkening of albedo**



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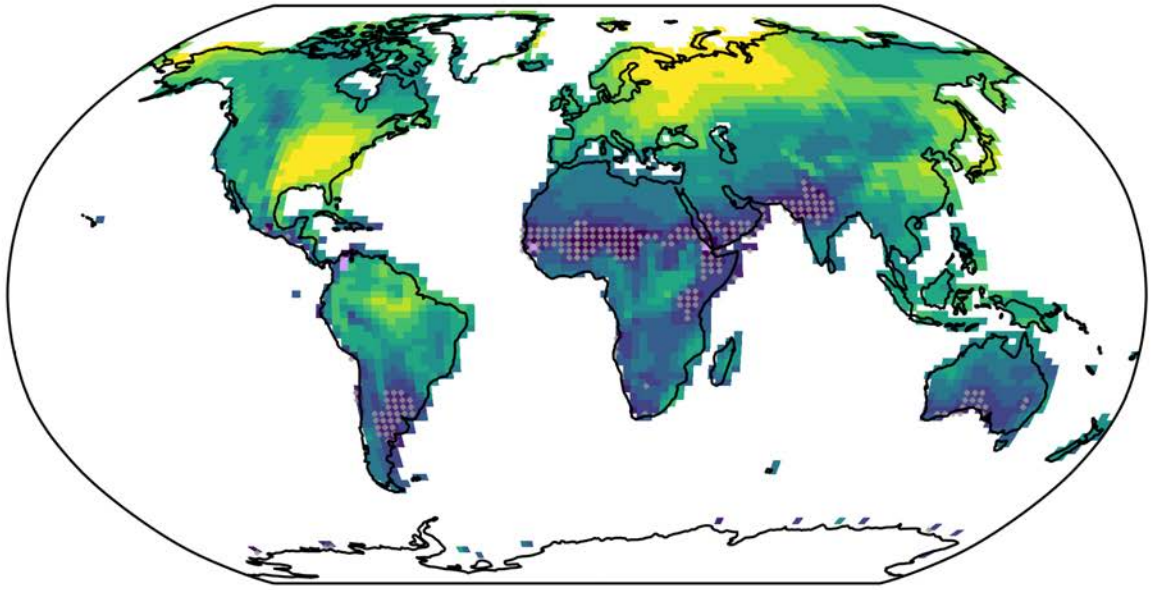

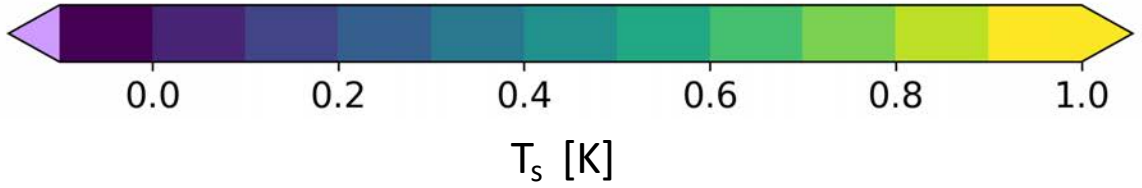

These surface properties are important not just for surface temperature, but for atmospheric circulation, too!

Changes in the atmospheric **energy potential χ**

Think of this as an implied change in atmospheric energy transport

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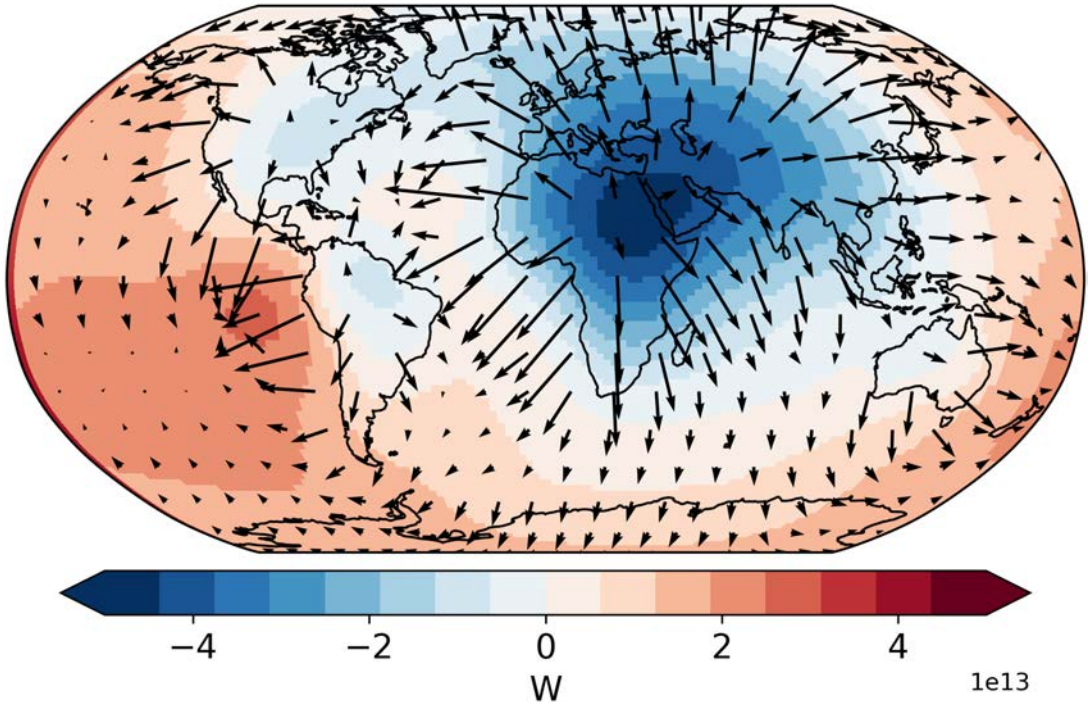
Change in **χ** for with decreased albedo



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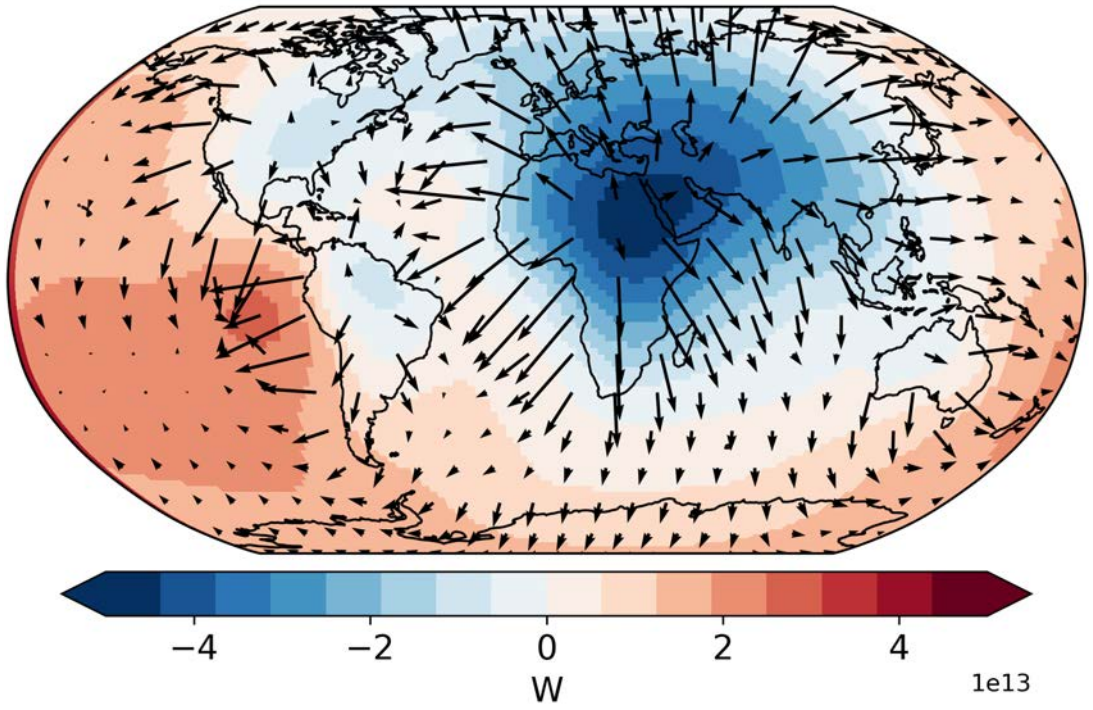

Decrease albedo = more energy into the atmosphere over all land surfaces

Energy moves away from land, towards oceans, but this is especially strong over land in the dry subtropics

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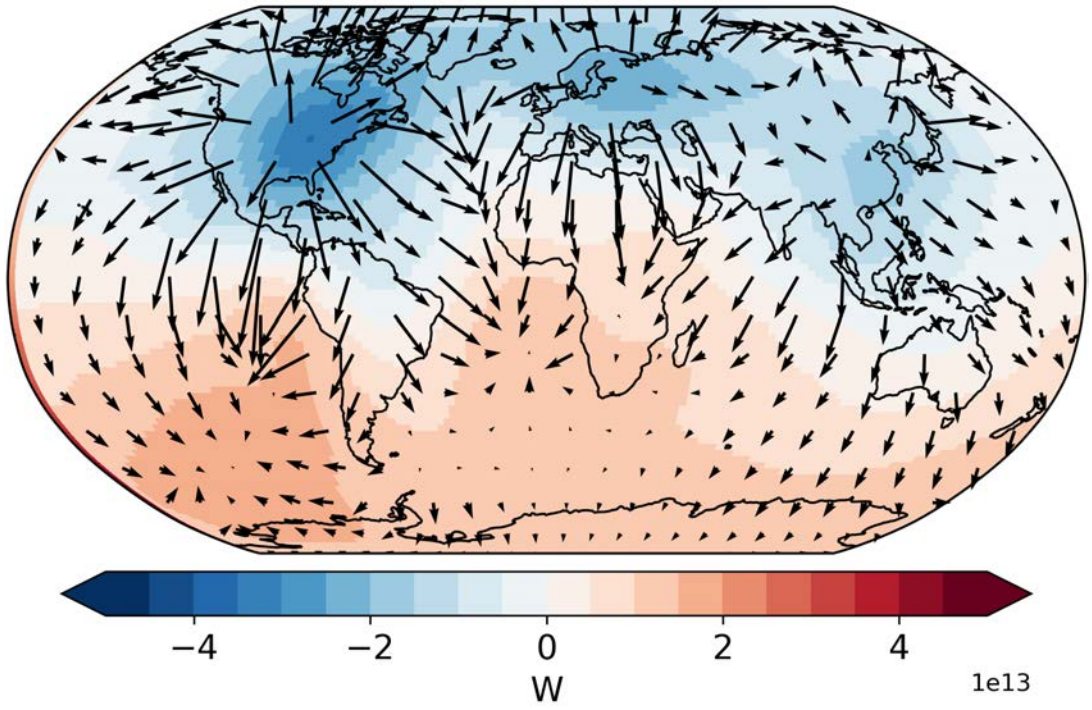
Changes in the atmospheric **energy potential χ**

Think of this as an implied change in atmospheric energy transport

Change in **χ** with increased evaporative resistance



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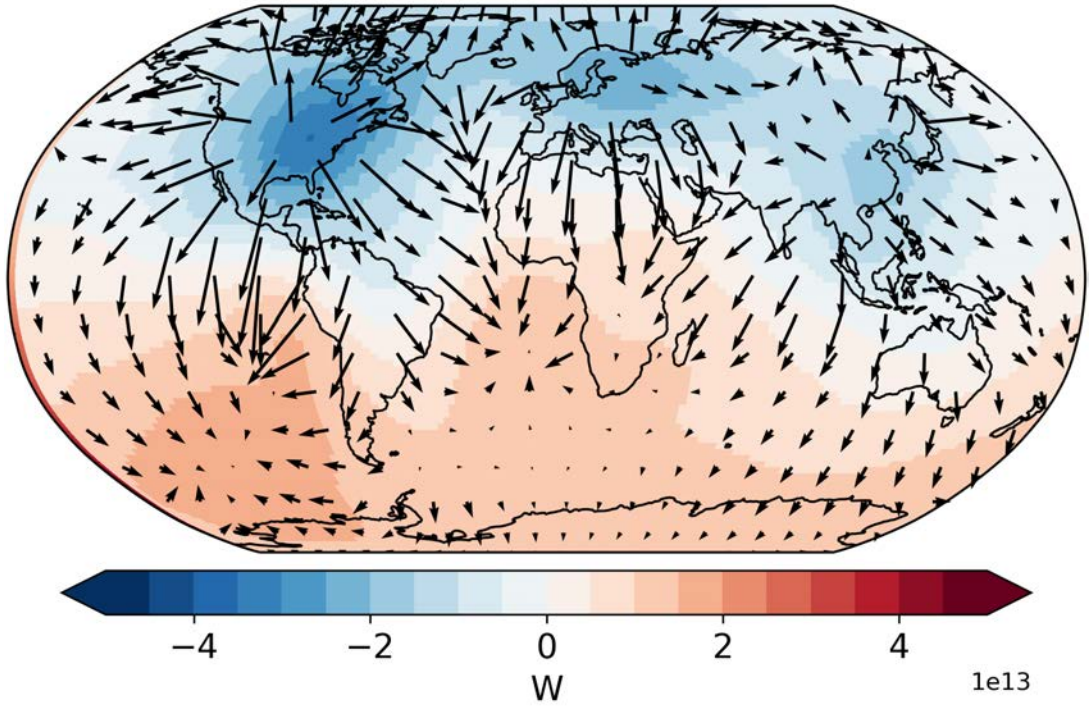


Evaporative resistance doesn't change the total amount of energy from the land into the atmosphere, it just repartitions it

… *unless* there is a change in cloud cover!

Summary

- Individual land surface properties have very distinct effects on the surface energy budget depending on the **location** of the change in “vegetation” (surface property)

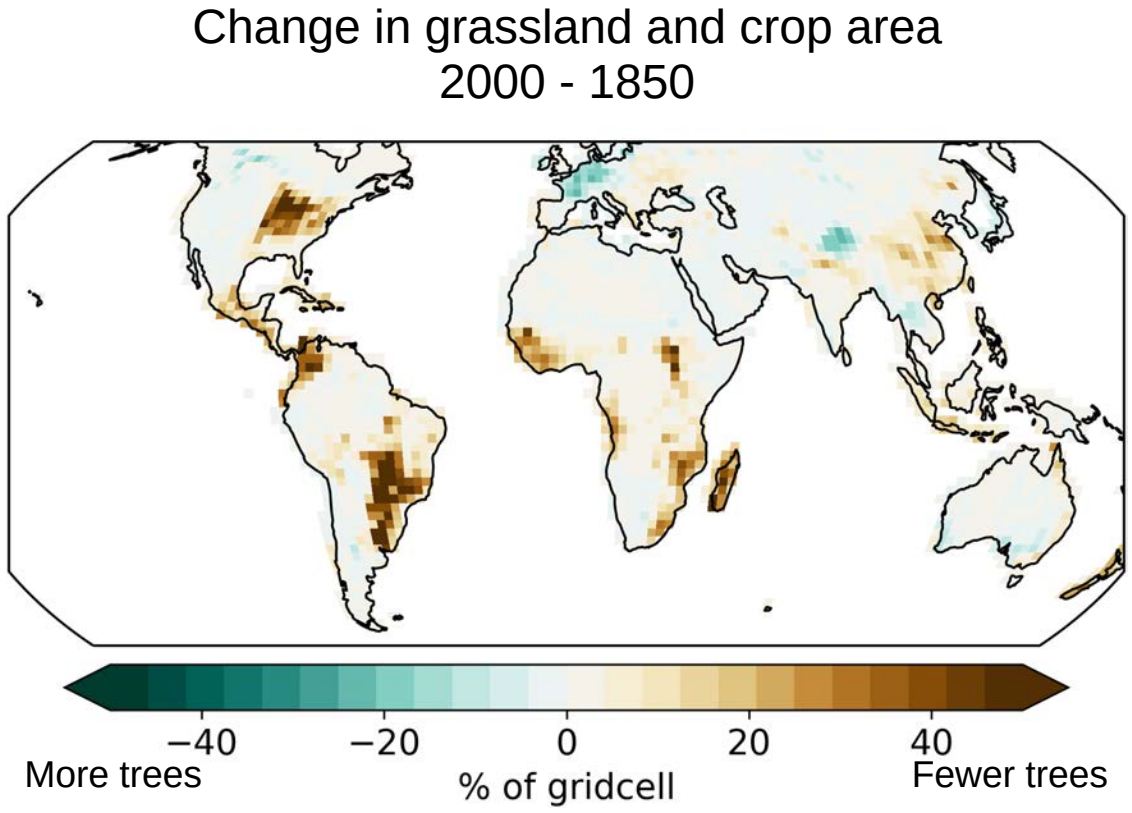
- This pattern comes in part from surface climate (e.g. wet vs dry places), but also is a result of **where the atmosphere** is sensitive to changes in land surface energy fluxes (e.g. big cloud feedbacks in the mid-latitudes)

- These changes in land surface properties are important not only for surface climate, but also for large-scale atmospheric circulation

Realistic land use

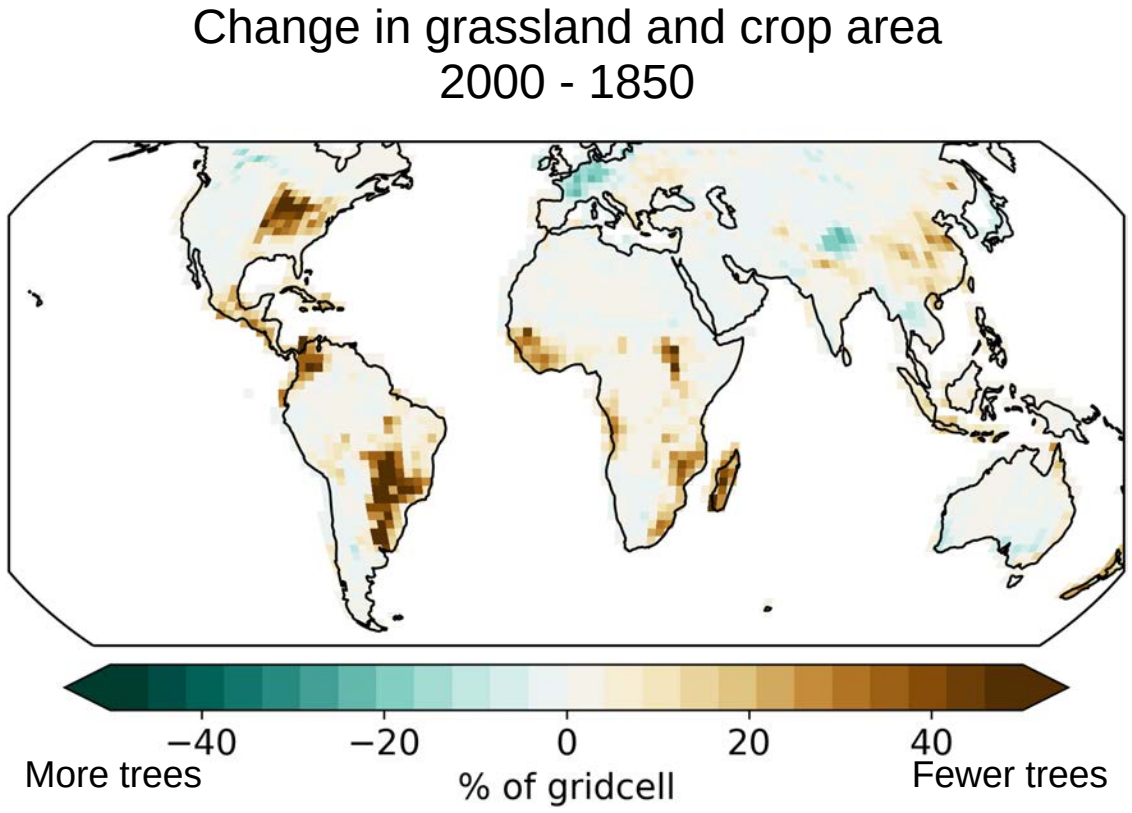
Idealized stuff is fun, but what if we consider a more plausible change in surface properties, such as the change in albedo & evaporative since 1850?

Land use change between 1850 and 2000: Mostly deforestation for agriculture



(From CLM)

Separating the effects of individual surface properties associated with historical vegetation change



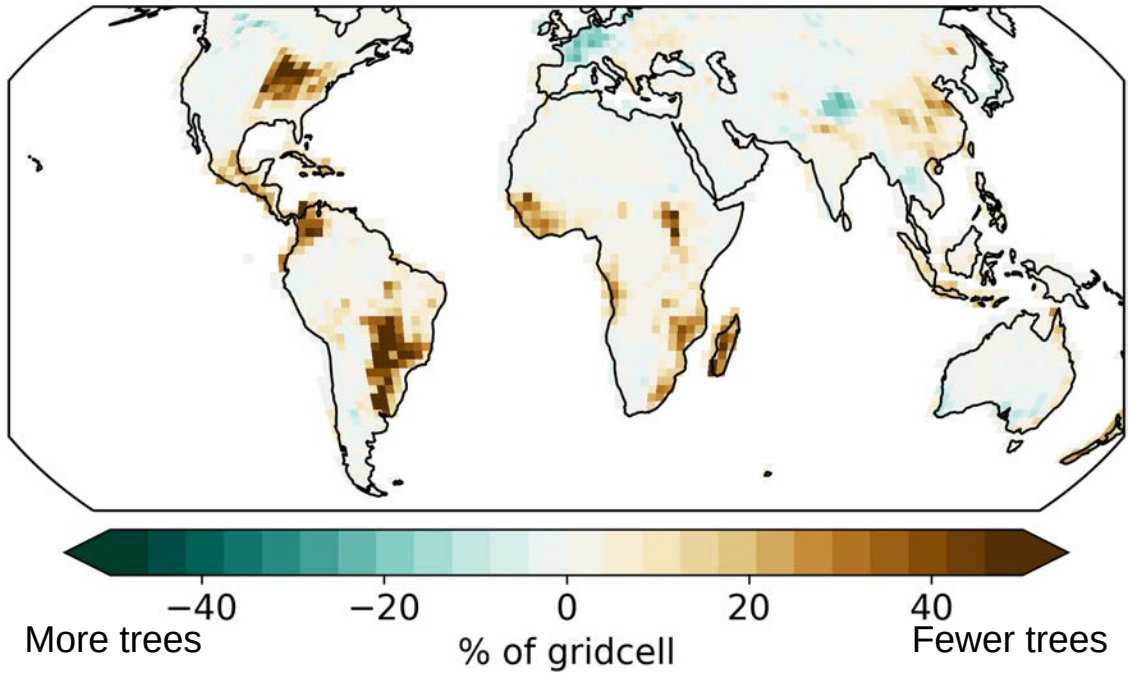
From a complex land model (CLM) diagnose the albedo and evaporative resistance corresponding to 1850 and 2000 vegetation maps

Impose the change in albedo and evaporative resistance into the idealized land model to isolate the effect of each

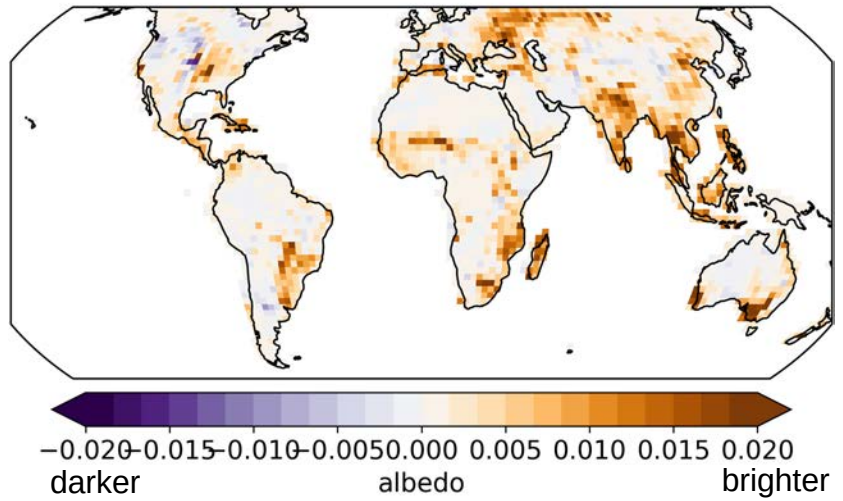
(From CLM)

Albedo change resulting from historical vegetation change (diagnosed from a complex land model)

Change in grassland and crop area
2000 - 1850



Change in albedo (2000 – 1850)



* caveat: only used summer albedo

Evaporative resistance change resulting from historical vegetation change (diagnosed from a complex land model)

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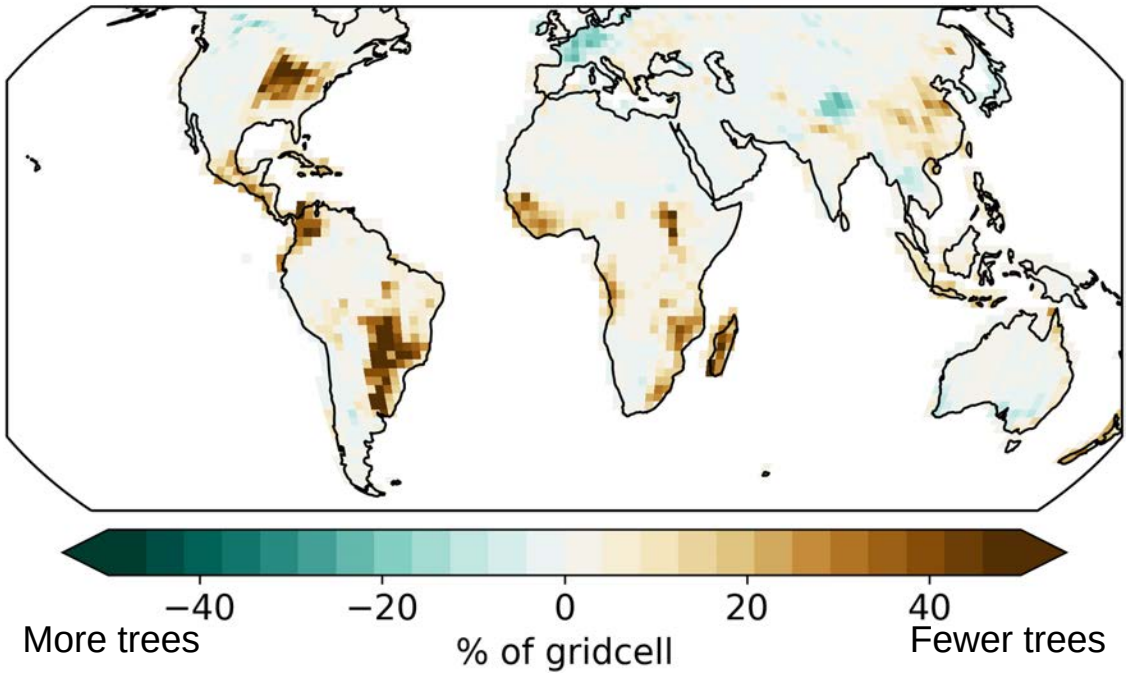

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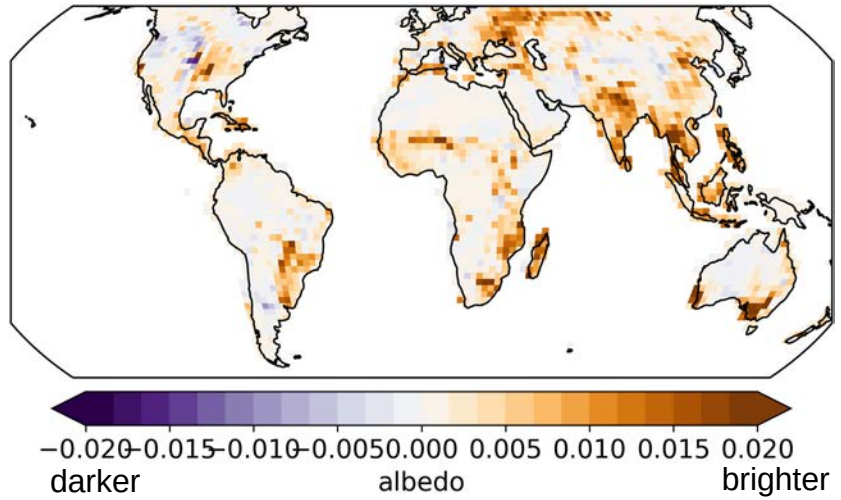
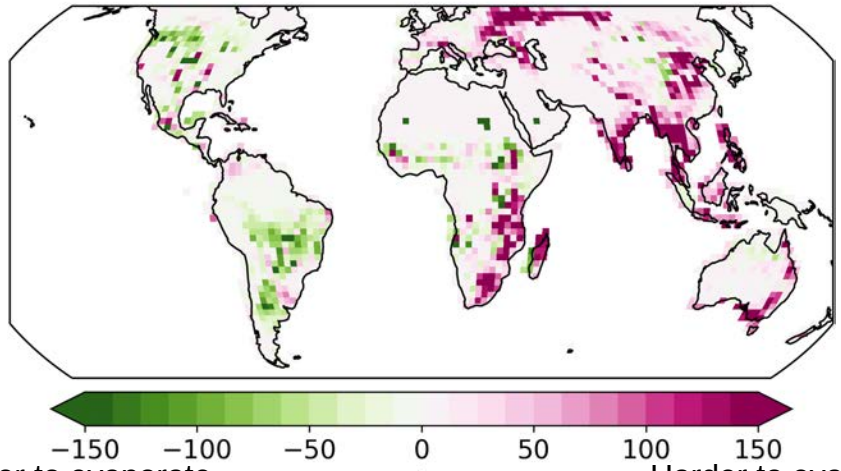


Change in evaporative resistance (2000 - 1850)



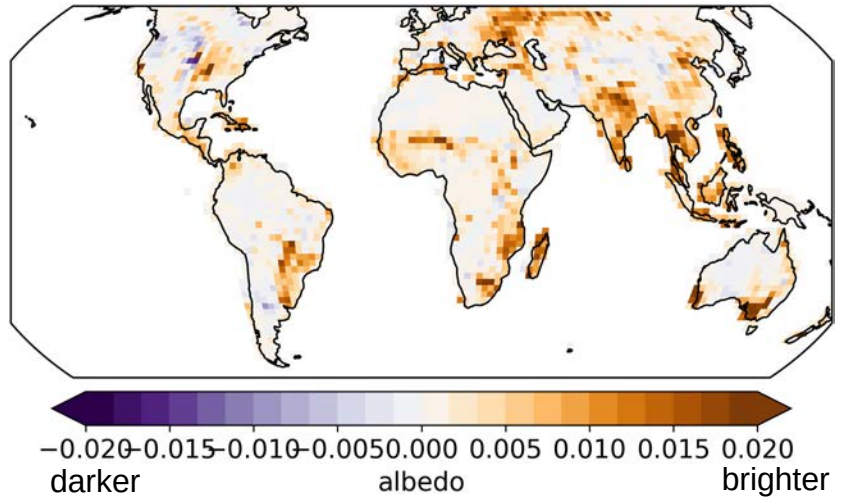
* caveat: only used summer, noon stomatal conductance

Albedo and **evaporative resistance** changes between 1850 and 2000

Diagnosed from a complex land model – we don't have observations for this!

See how each of these changes individually changes surface temperature

Change in albedo (2000 – 1850)



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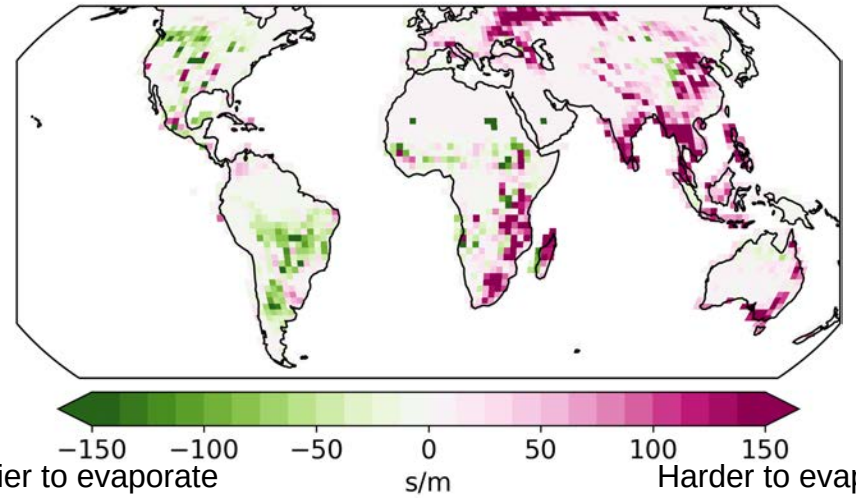
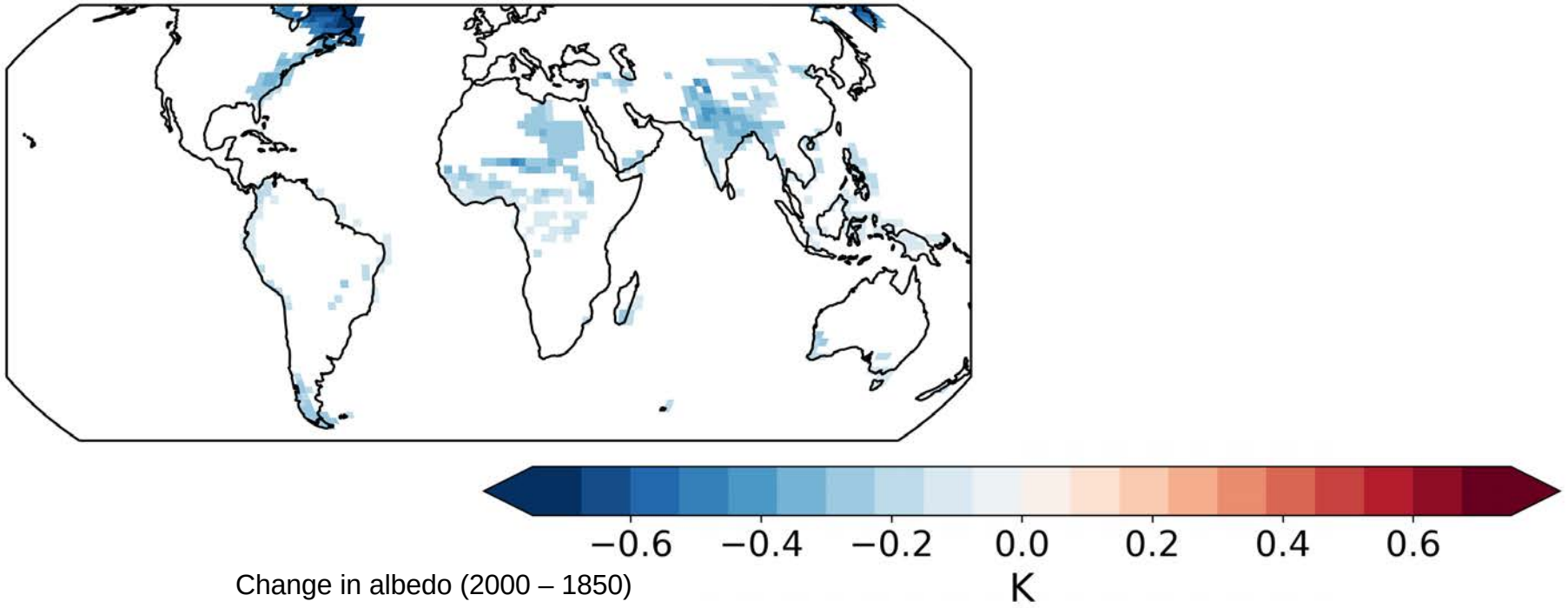
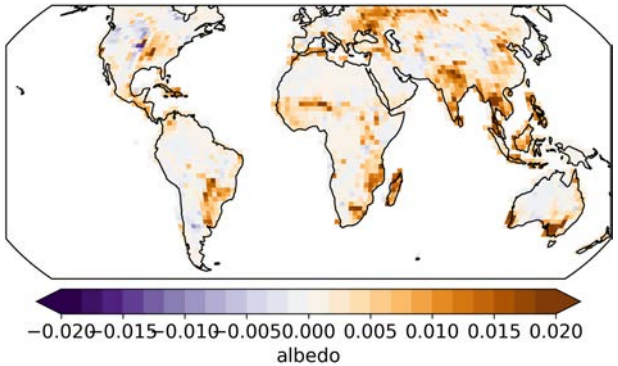


Change in
2m Air Temperature (2000 – 1850)

ΔT for Albedo, 2000 - 1850

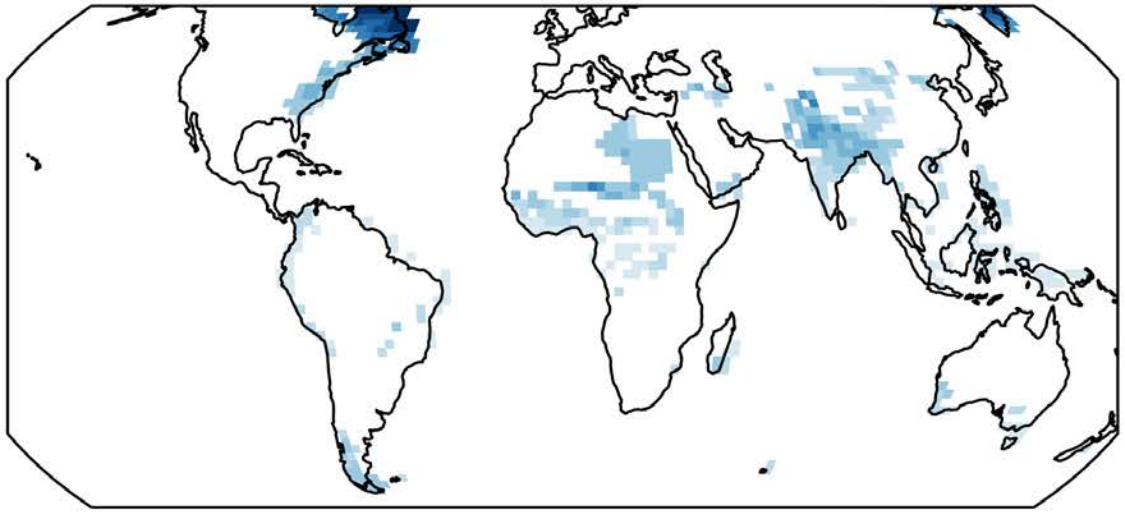


Change in albedo (2000 – 1850)

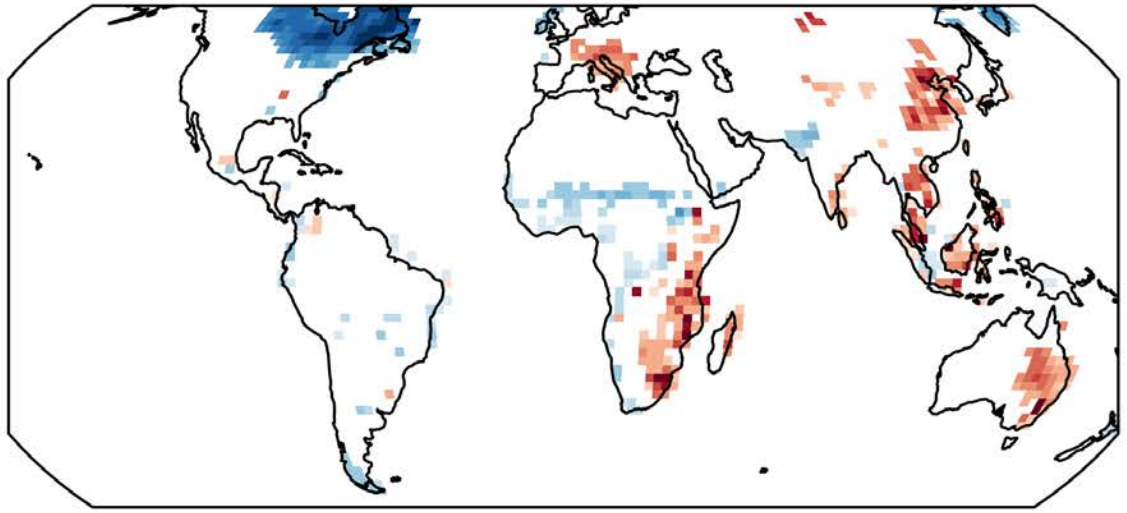


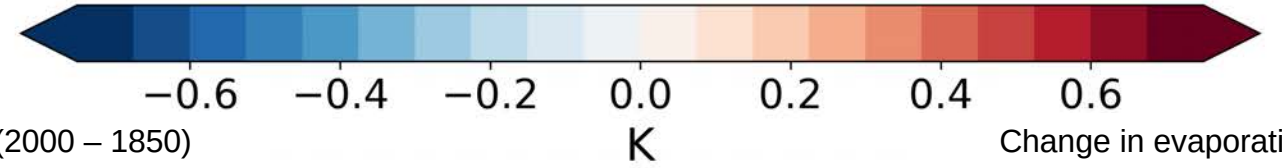
Change in
2m Air Temperature (2000 – 1850)

ΔT for Albedo, 2000 - 1850

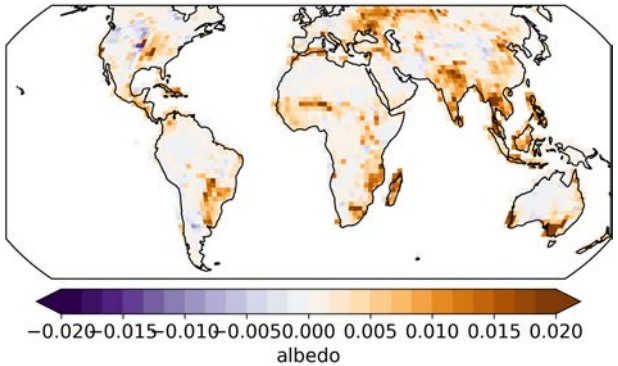


ΔT for Evaporative Resistance 2000 - 1850

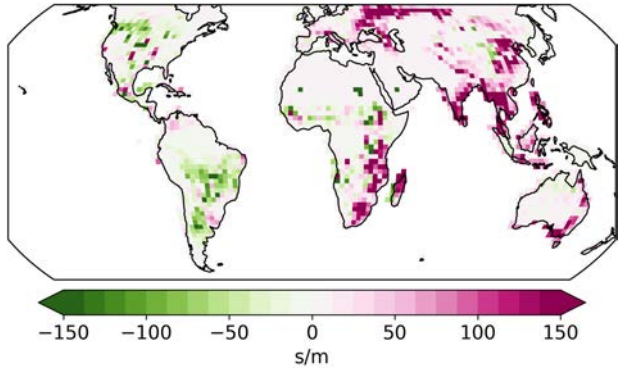




Change in albedo (2000 – 1850)

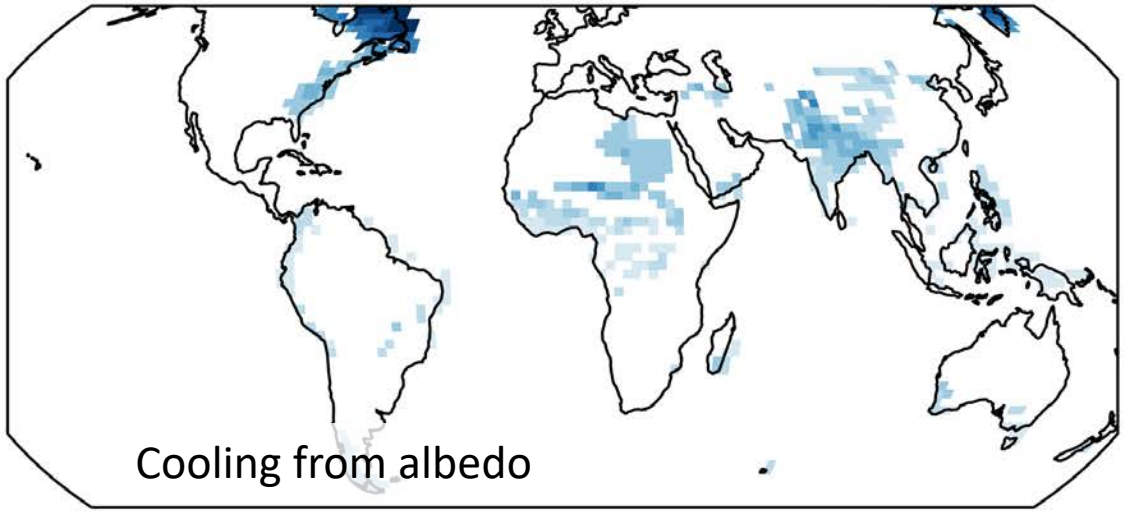


Change in evaporative resistance (2000 - 1850)

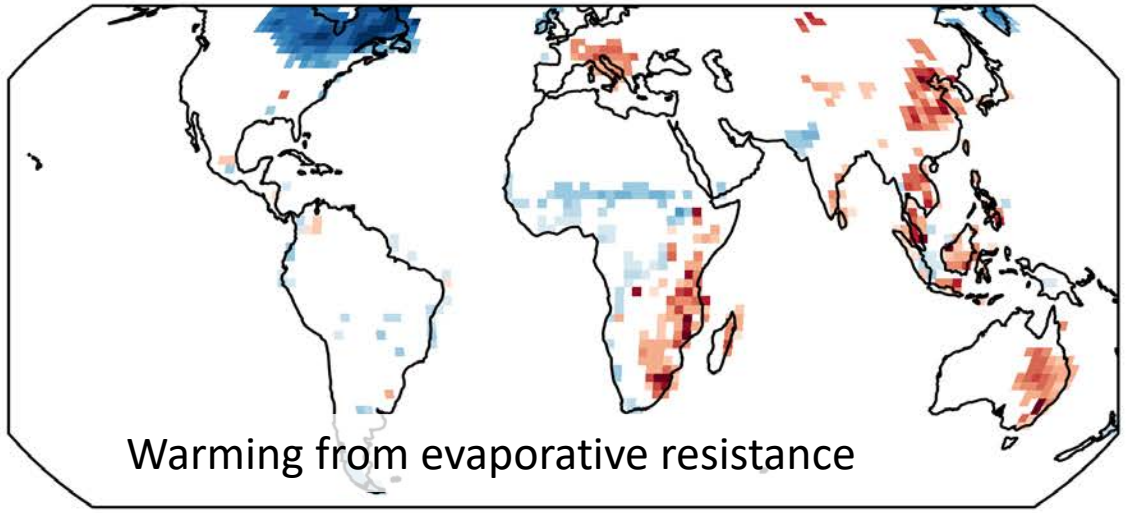


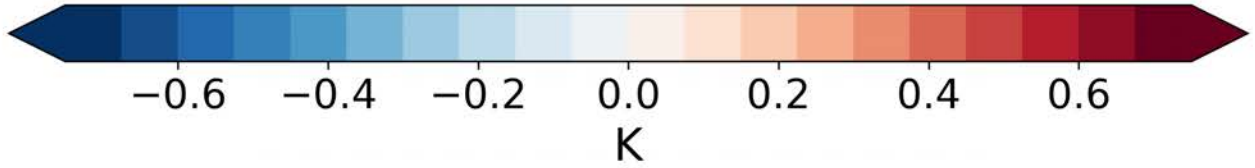
Change in 2m Air Temperature driven by **albedo** vs **evaporative resistance** for historical vegetation change (2000 – 1850)

ΔT for Albedo, 2000 - 1850



ΔT for Evaporative Resistance 2000 - 1850





Warming from changes in evaporative resistance is **larger** than **cooling** from changes in albedo!

Summary

- Individual land surface properties have very distinct effects on the surface energy budget depending on the **location** of the change in “vegetation” (surface property)

- This pattern comes in part from surface climate (e.g. wet vs dry places), but also is a result of **where the atmosphere** is sensitive to changes in land surface energy fluxes (e.g. big cloud feedbacks in the mid-latitudes)

- These changes in land surface properties are important not only for surface climate, but also for large-scale atmospheric circulation

To diagnose the historical change in **albedo** and **evaporative resistance**, use two complex land model simulations (don't have observations for this!)

CLM-CAM5

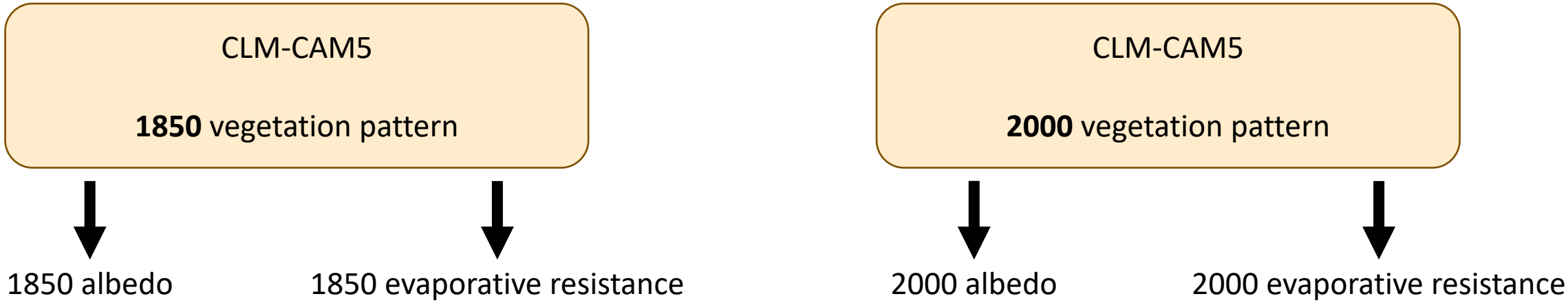
1850 vegetation pattern

CLM-CAM5

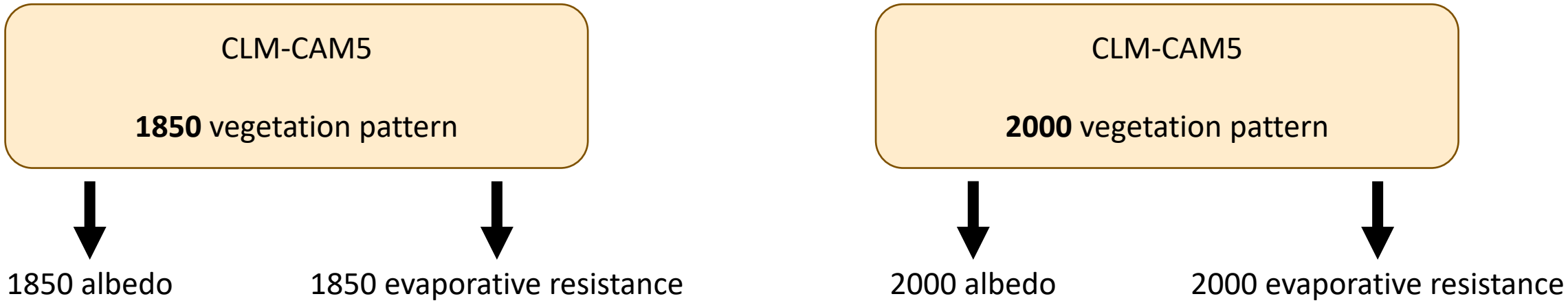
2000 vegetation pattern

Everything else between these simulations is identical (CO_2, ocean heat transport, etc)

To diagnose the historical change in **albedo** and **evaporative resistance**, use two complex land model simulations (don't have observations for this!)



Use the diagnosed 1850 and 2000 values for albedo and evaporative resistance to separate the effects of each property using SLIM

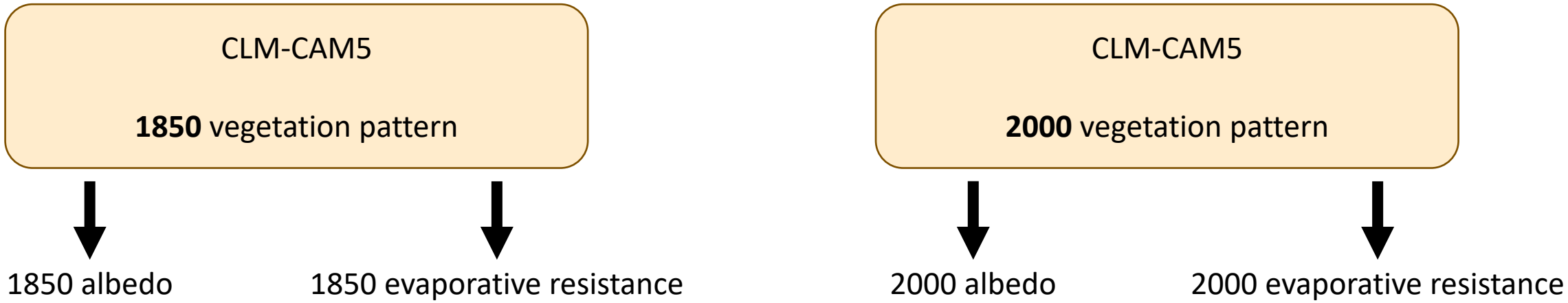


Two SLIM-CAM5 simulations to isolate impact of **albedo** change on climate:

SLIM-CAM5
1850 albedo
1850 evaporative resistance

SLIM-CAM5
2000 albedo
1850 evaporative resistance

Use the diagnosed 1850 and 2000 values for albedo and evaporative resistance to separate the effects of each property using SLIM



Two SLIM-CAM5 simulations to isolate impact of **albedo** change on climate:

SLIM-CAM5
1850 albedo
1850 evaporative resistance

SLIM-CAM5
2000 albedo
1850 evaporative resistance

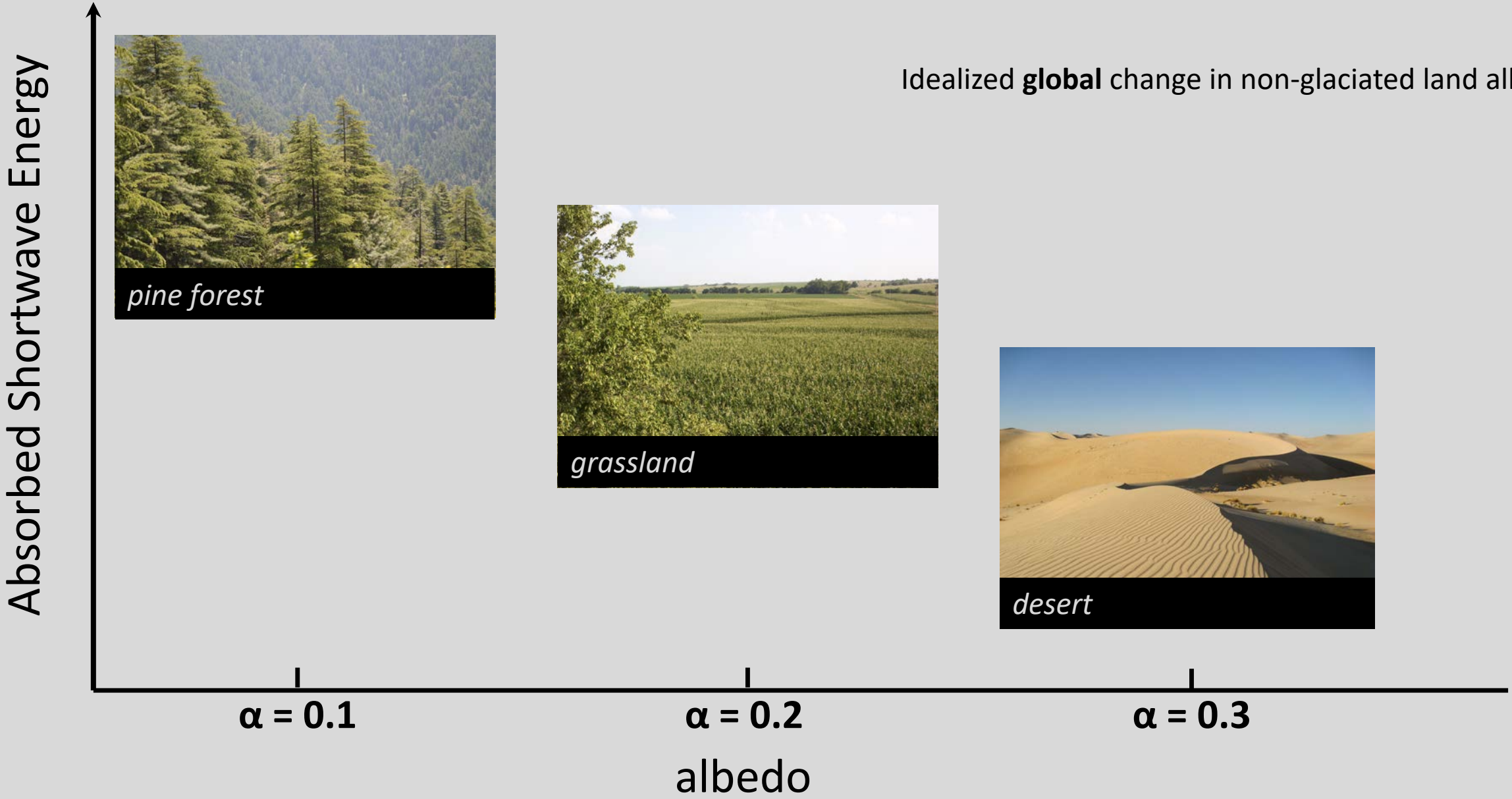
Two more SLIM-CAM5 simulations to isolate impact of **evaporative resistance** change on climate:

SLIM-CAM5
1850 albedo
1850 evaporative resistance

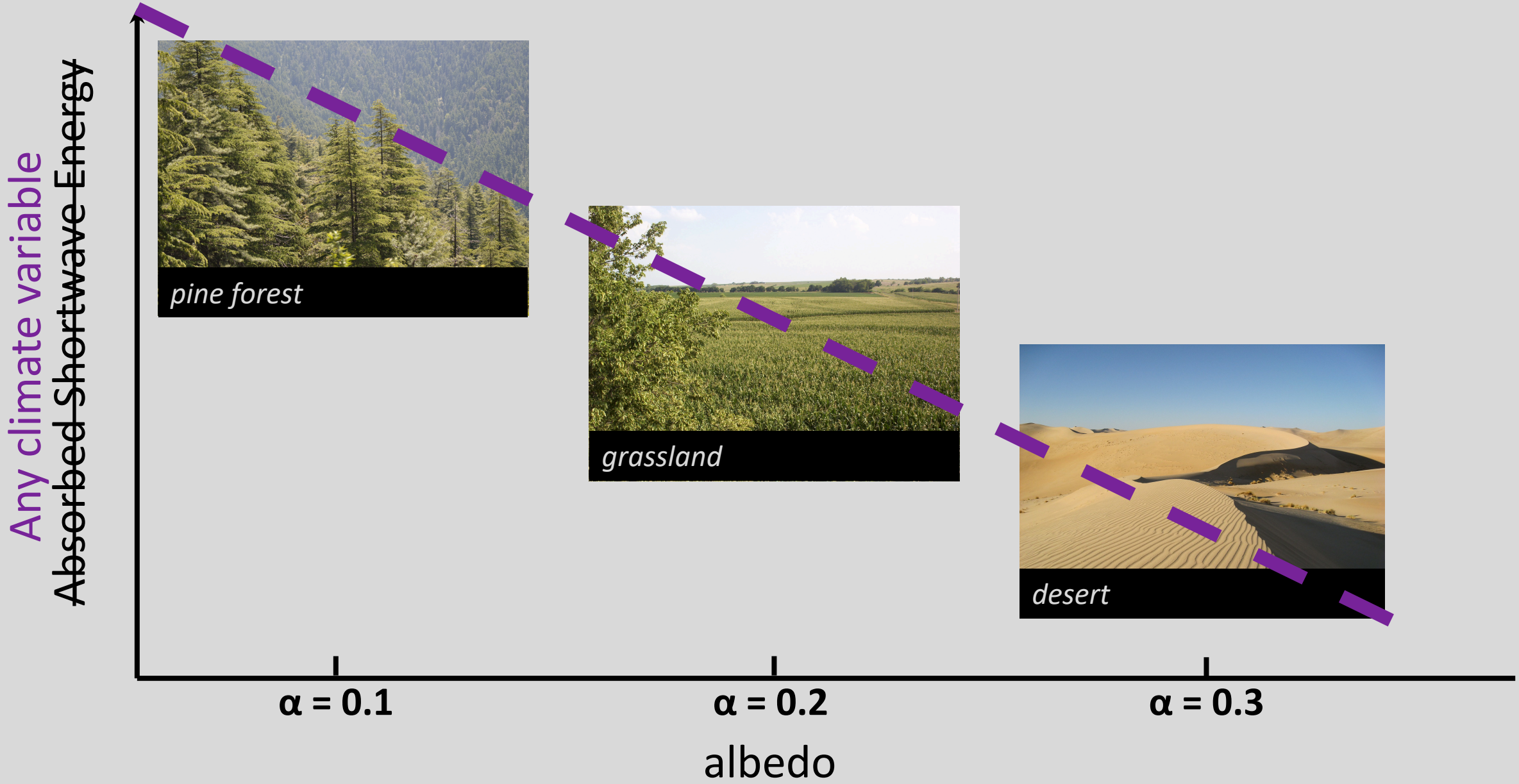
SLIM-CAM5
1850 albedo
2000 evaporative resistance

Isolate the climate effect (**offline** and **coupled**) of land **albedo**

Idealized **global** change in non-glaciated land albedo



Fit a linear relationship between **climate** (e.g. T, or surface energy flux) and **albedo**



Slope of this line = **change in climate** per **change in albedo**