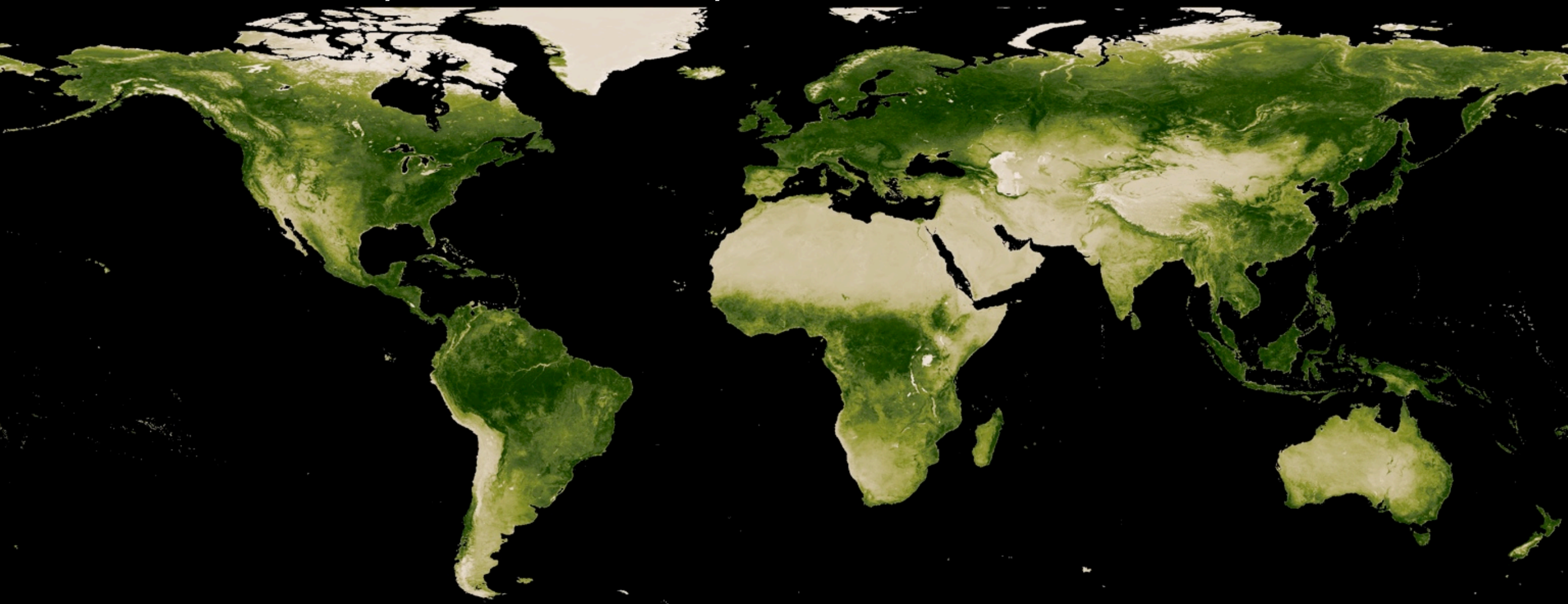
Quantifying the Role That Terrestrial Ecosystems Play in Earth's Climate



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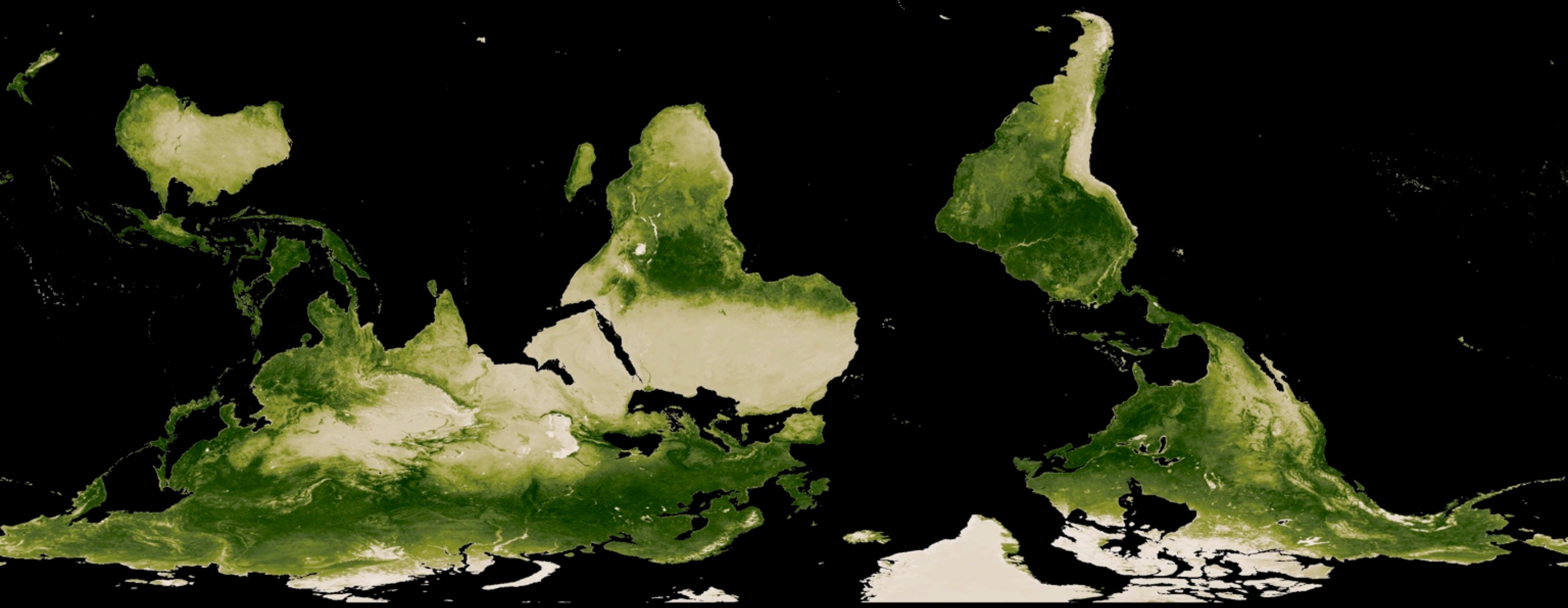
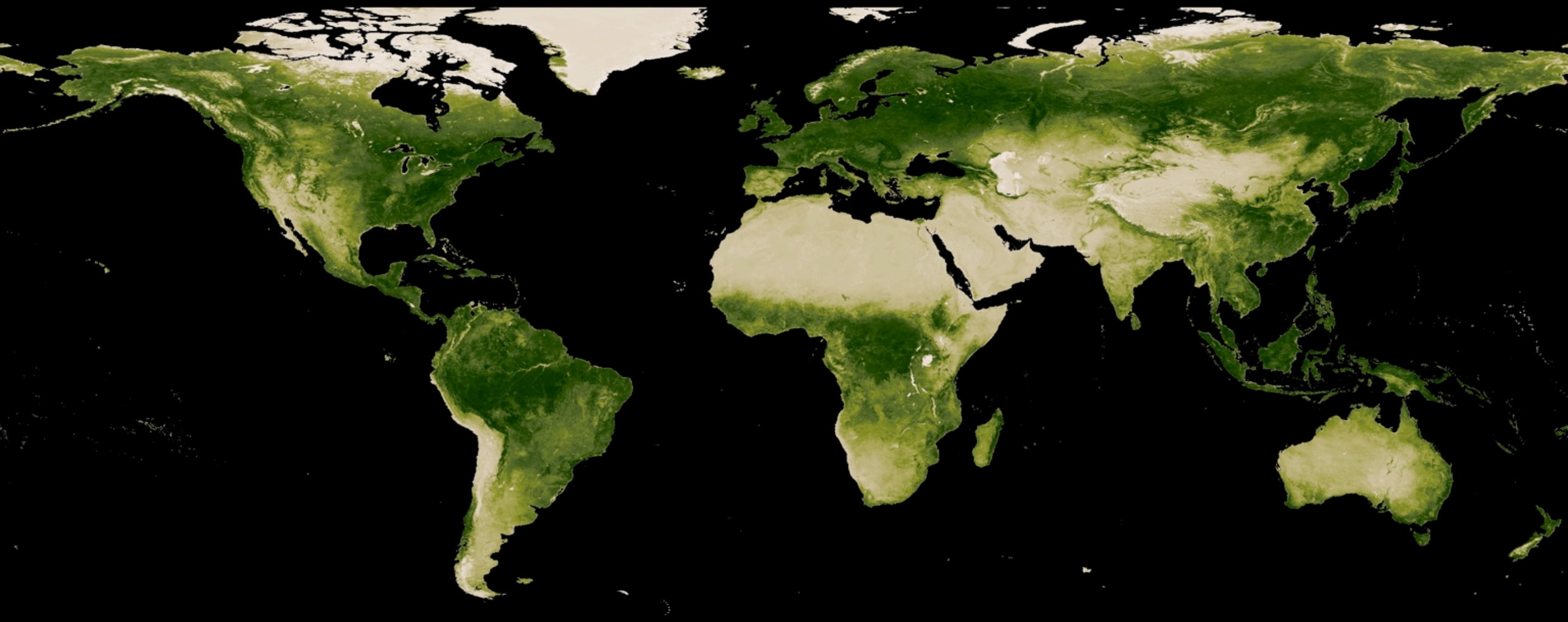
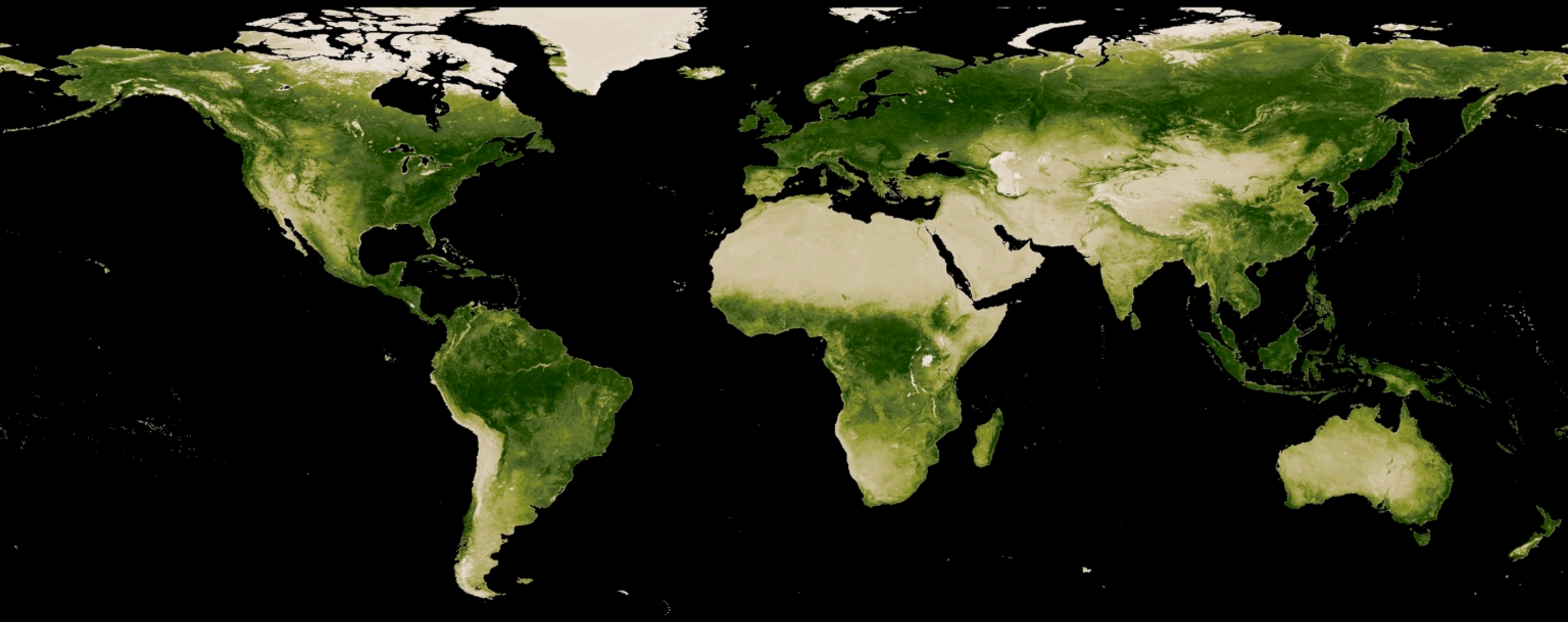
Funding from NSF



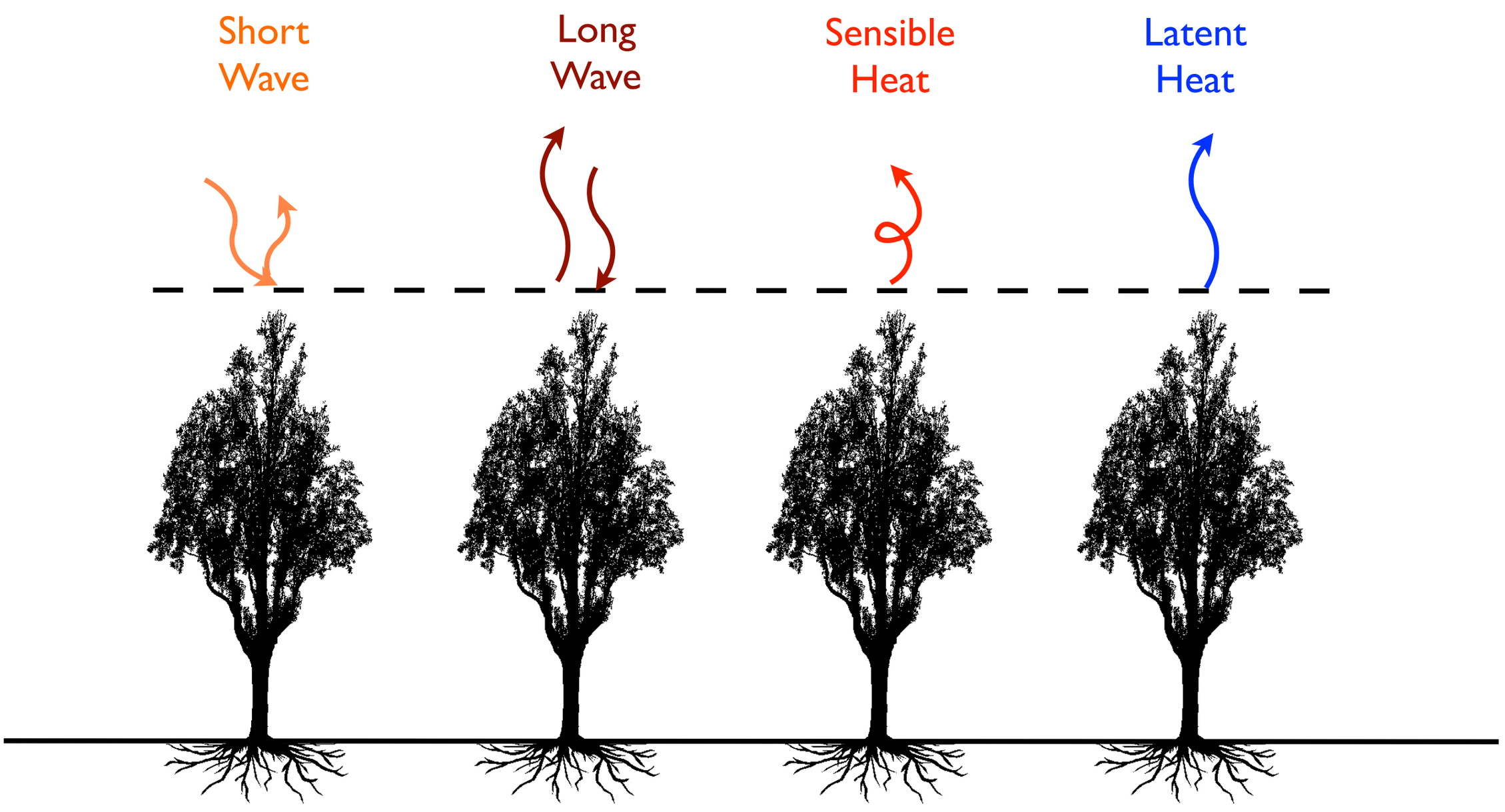
Plants ⟷ Climate



Where and *How* do plants influence climate?

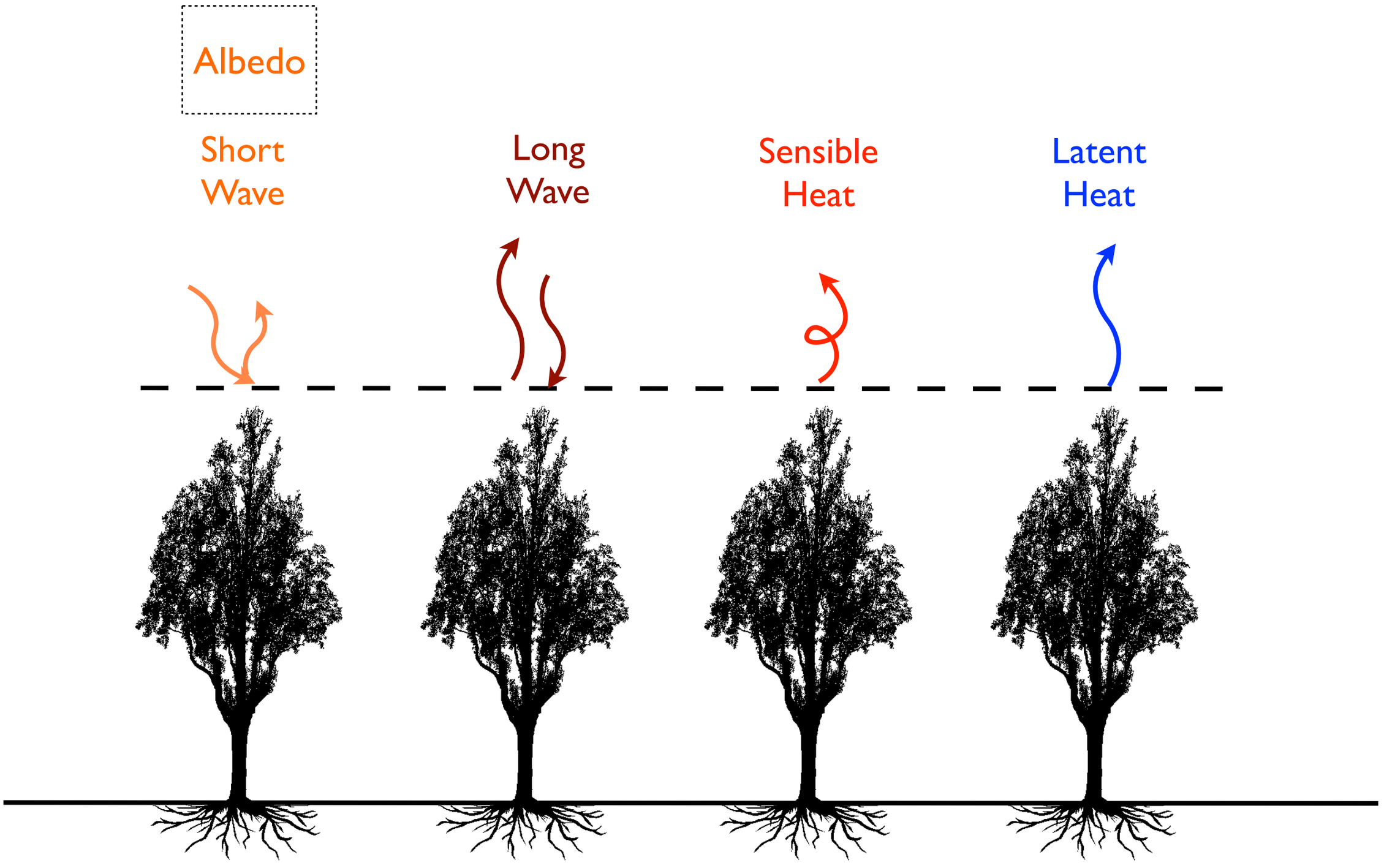


How do Plants and Climate Interact?



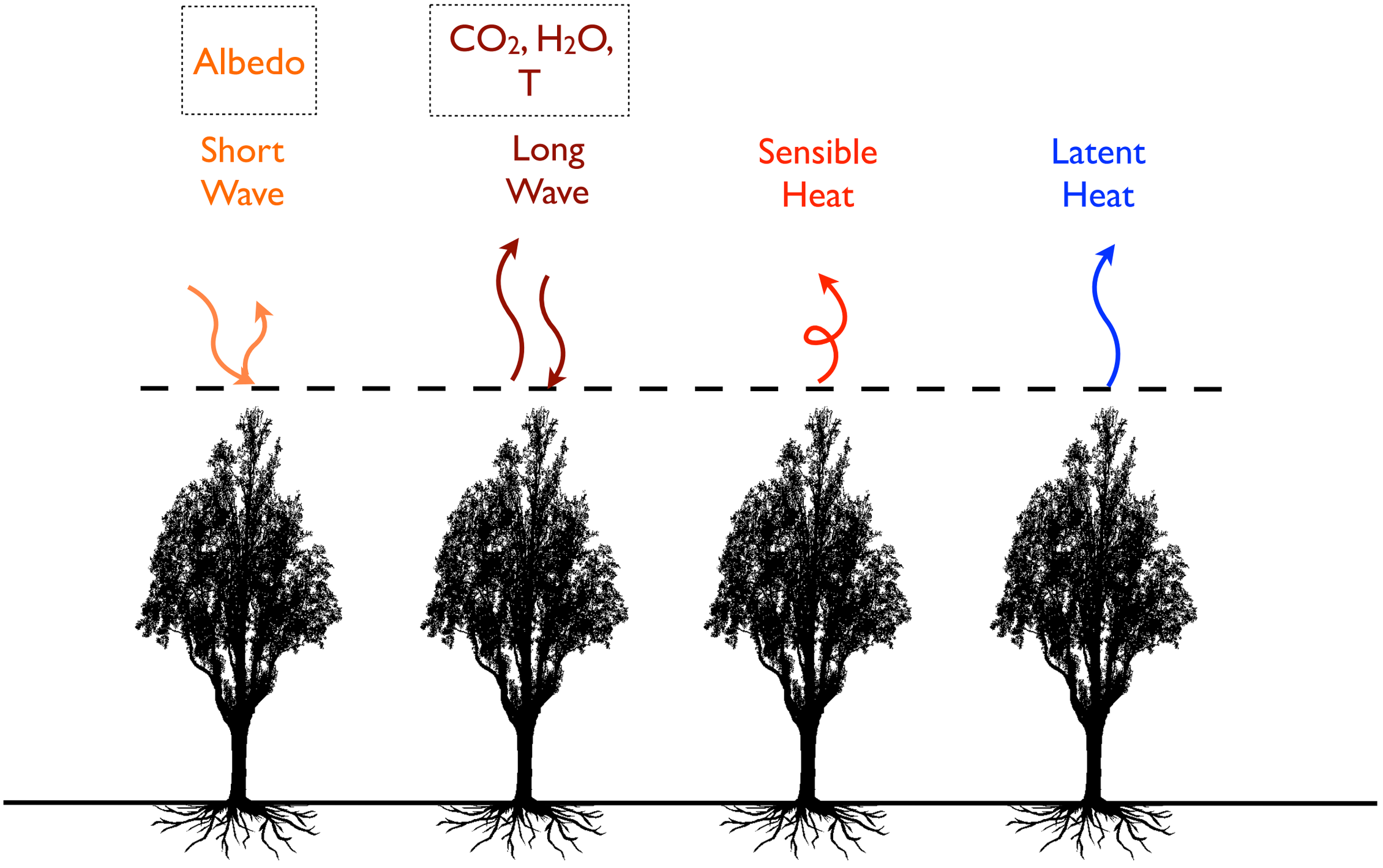
Terrestrial Surface Energy Budget

How do Plants and Climate Interact?



Albedo varies by plant type

How do Plants and Climate Interact?



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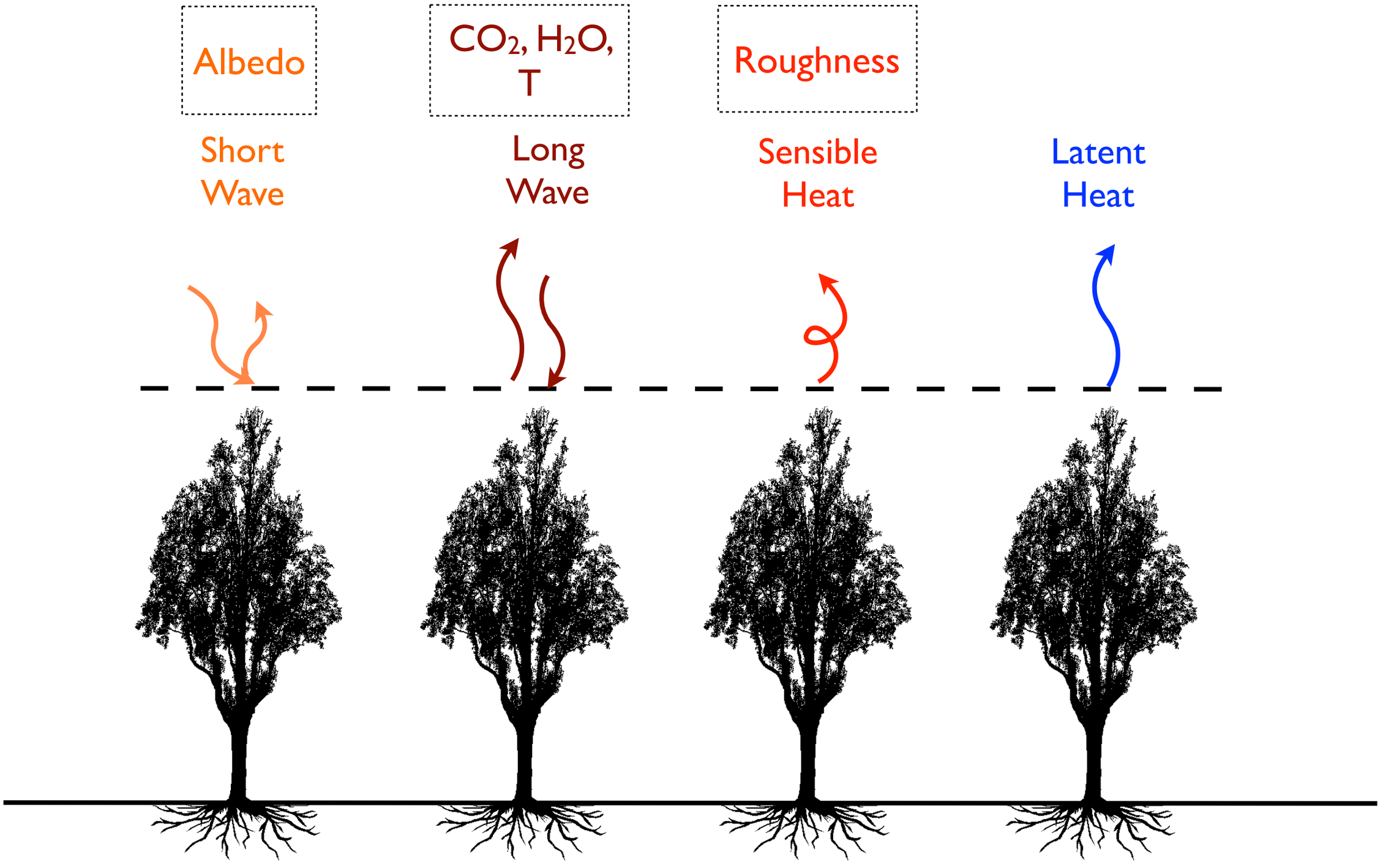

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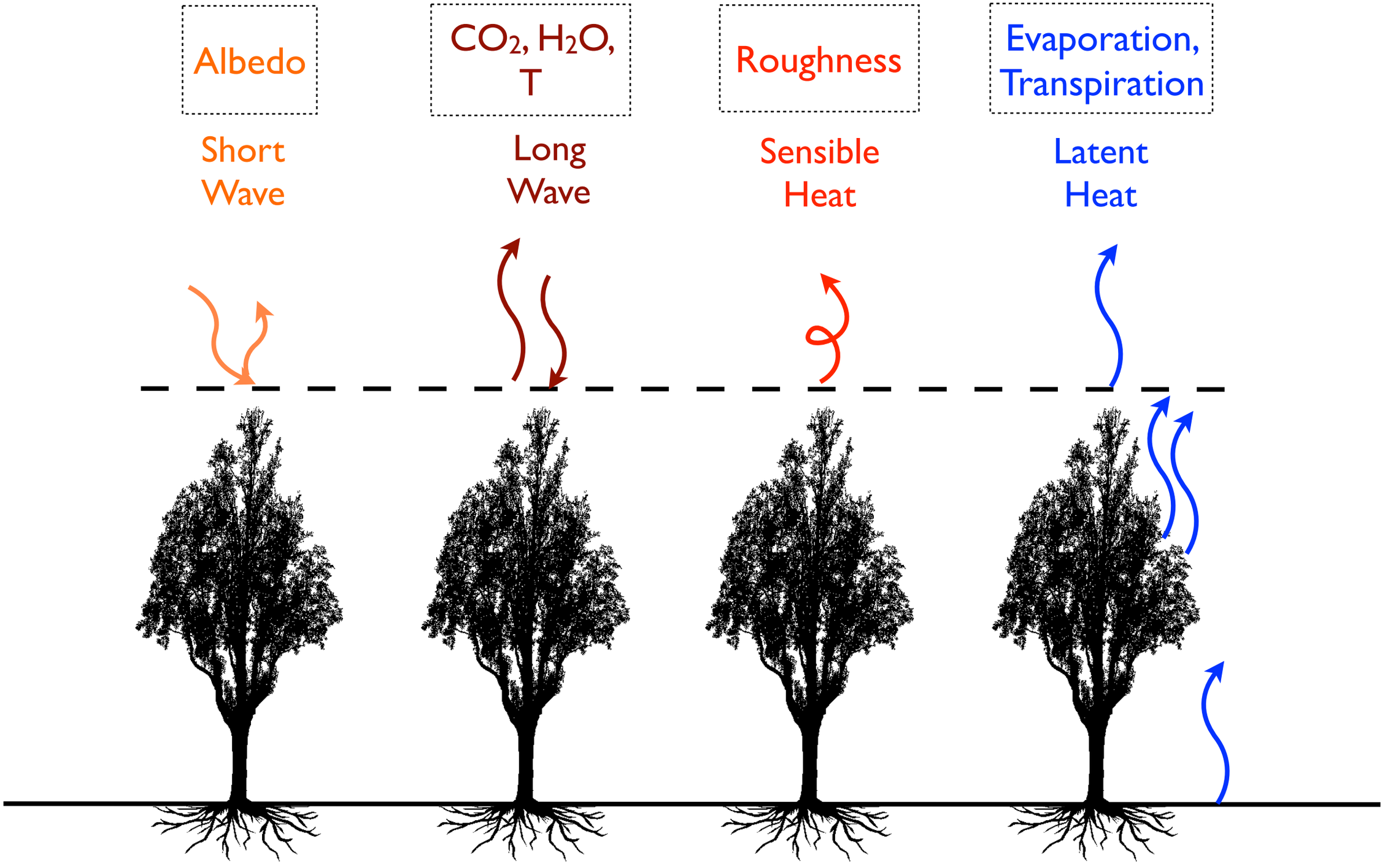
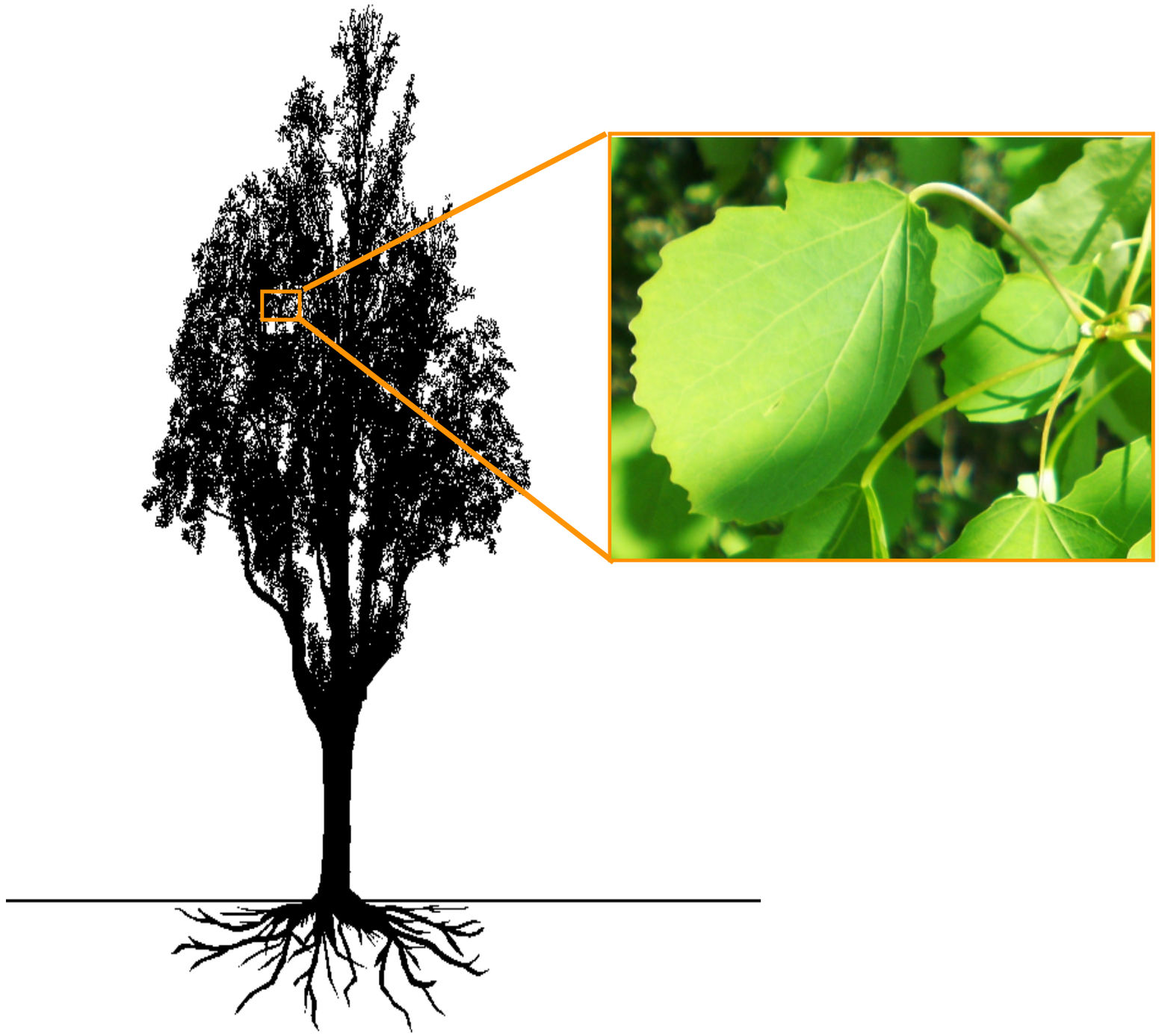


Transpiration flux of water

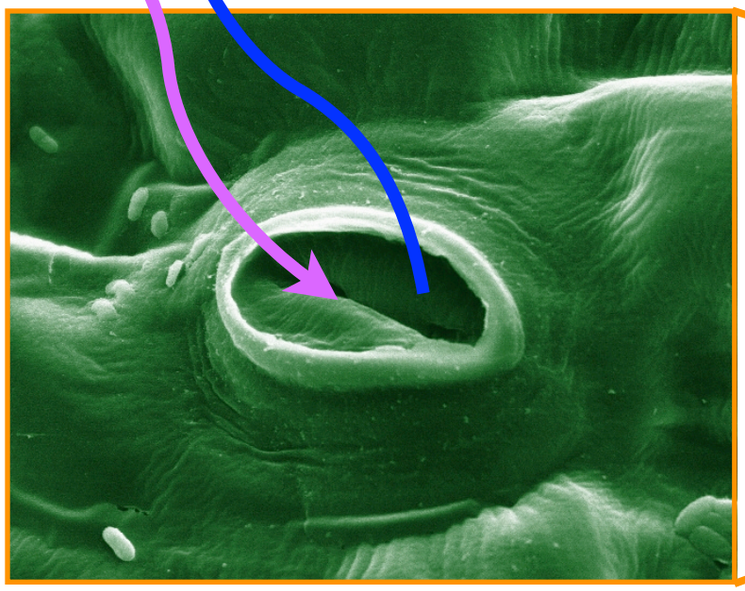


Photos: Wikimedia Commons

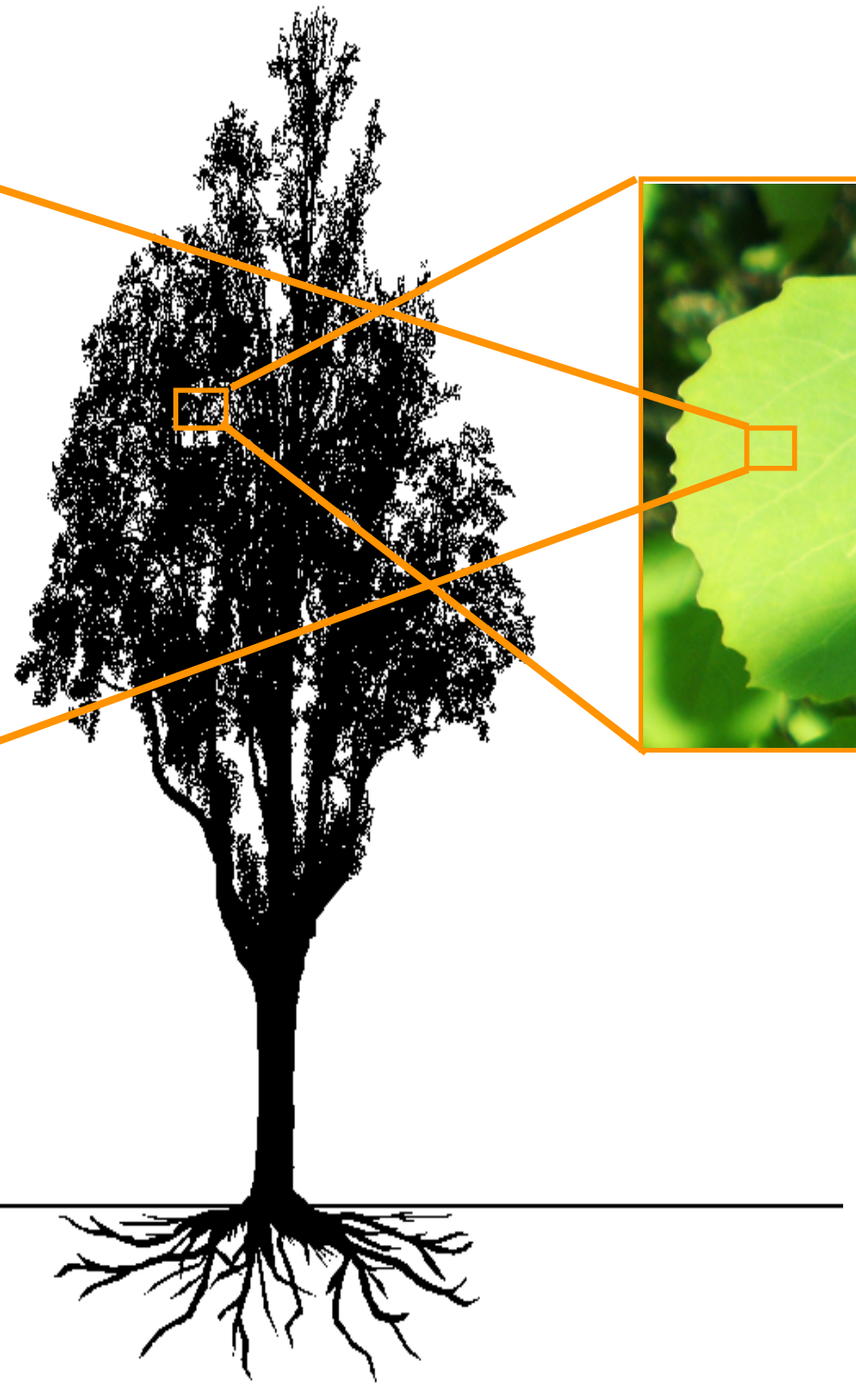
Carbon in, water out

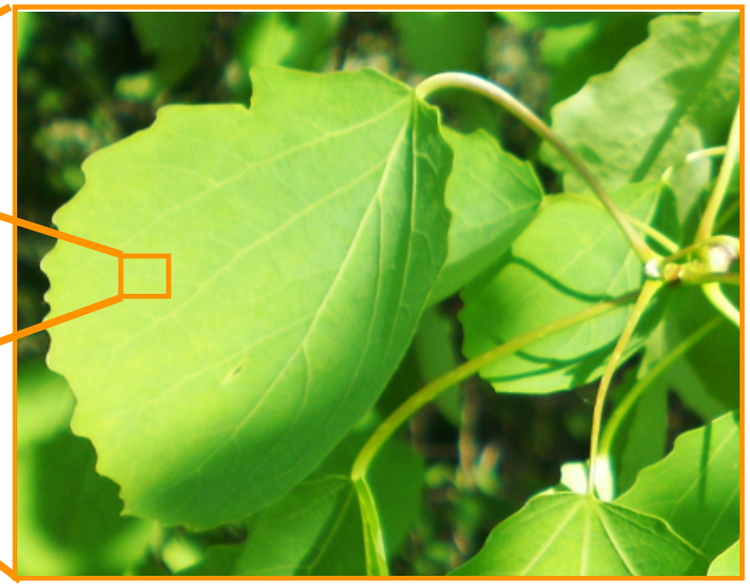
Photosynthesis
CO_2

Transpiration
H_2O



Stomata





Leaf

Photos: Wikimedia Commons

ΔPlants => ΔSurface Energy Budget

Albedo

CO_2, H_2O, T

Roughness

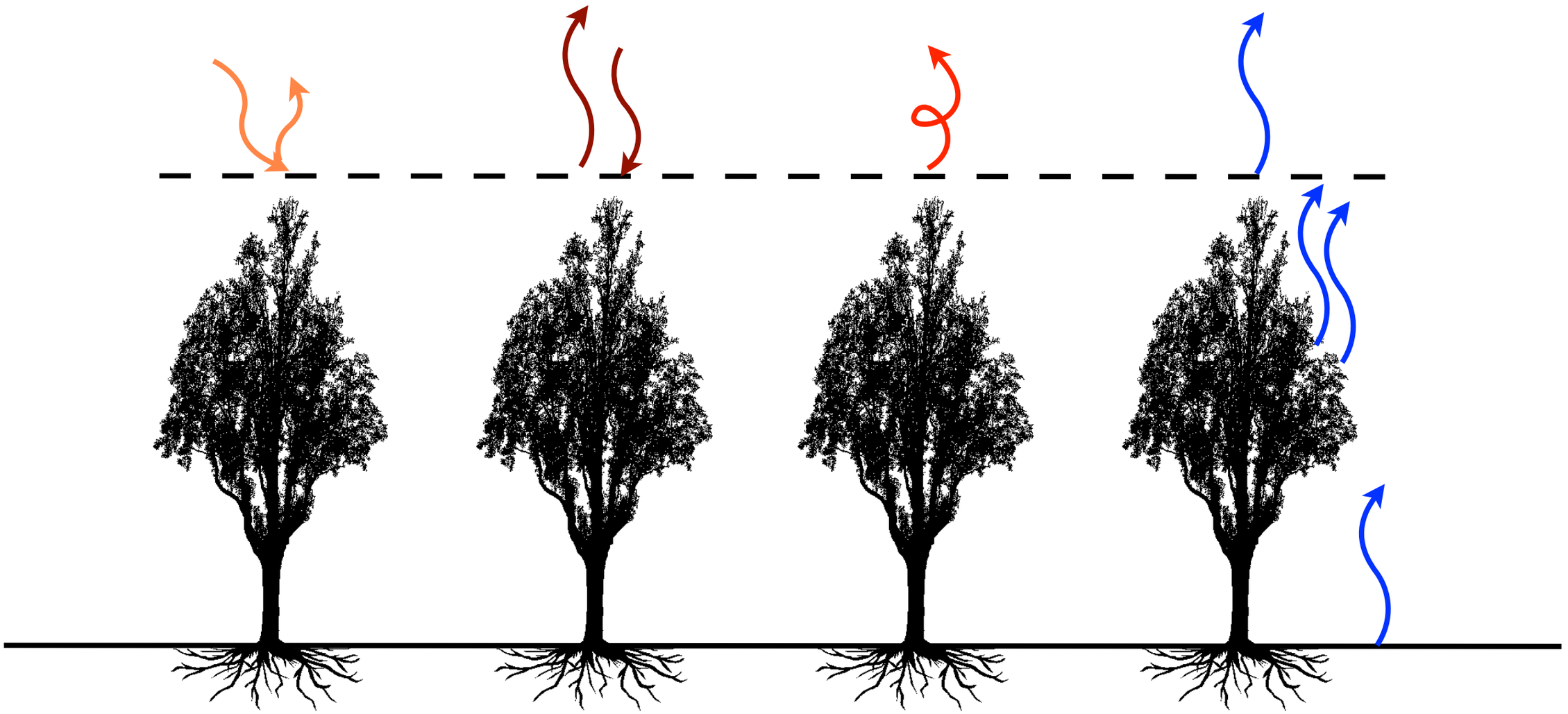
Evaporation, Transpiration

Short Wave

Long Wave

Sensible Heat

Latent Heat



Why does this matter?

Climate changes influence plants

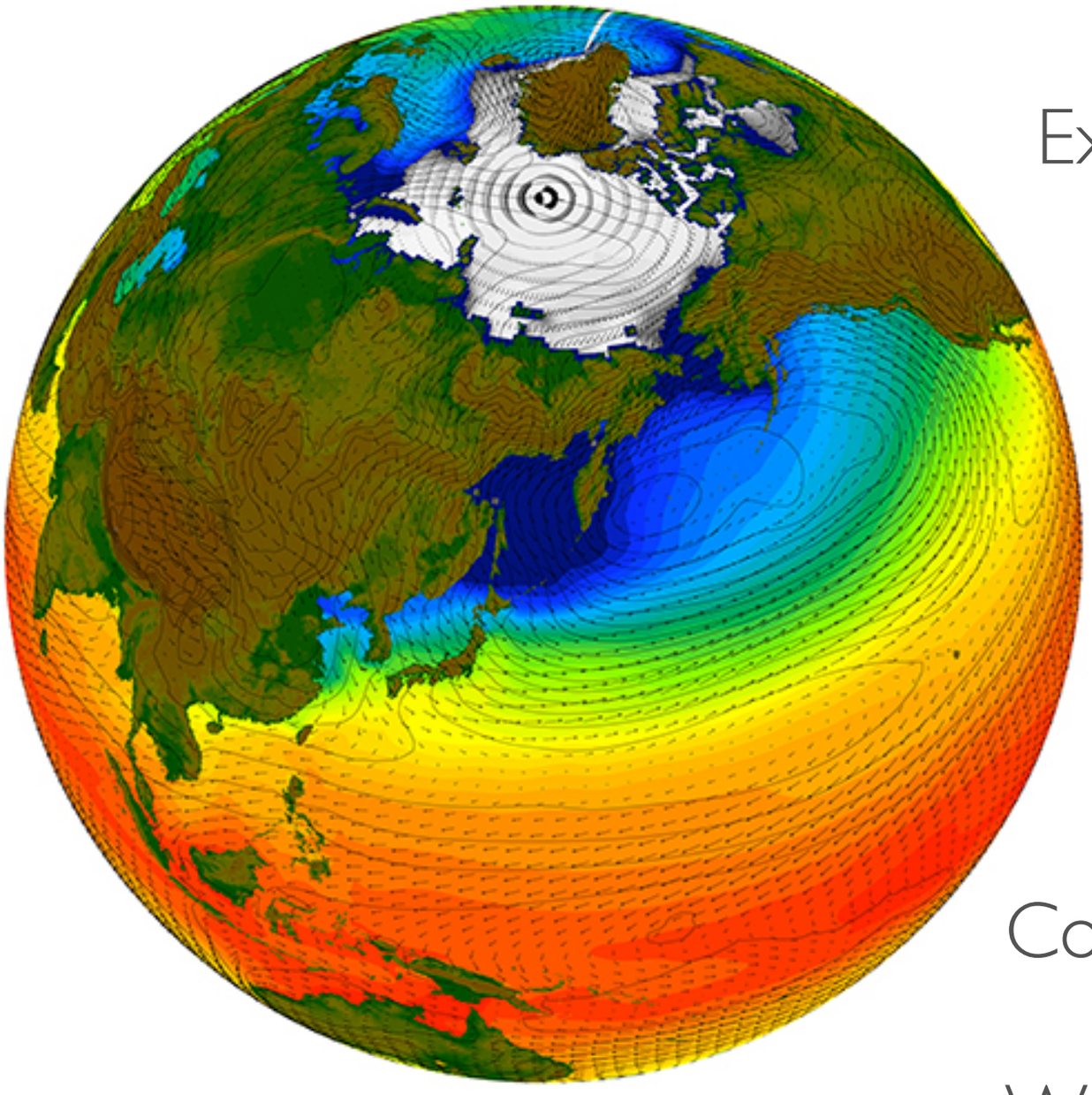
- Increasing temperature => more growth
- CO_2 fertilization => more growth?
- Changing hydrology and geomorphology => ?

=> changes in albedo, evaporative resistance, plant type etc.

Quantifying the role that terrestrial ecosystems play in Earth's climate

1. Changing Arctic Plant cover and types?
2. Land surface properties globally

Simulations allow us to ask theoretical questions



Experiments:

Δvegetation or

Δsurface properties

Compare with a control world

We typically use a slab ocean

Quantifying the role that terrestrial ecosystems play in Earth's climate

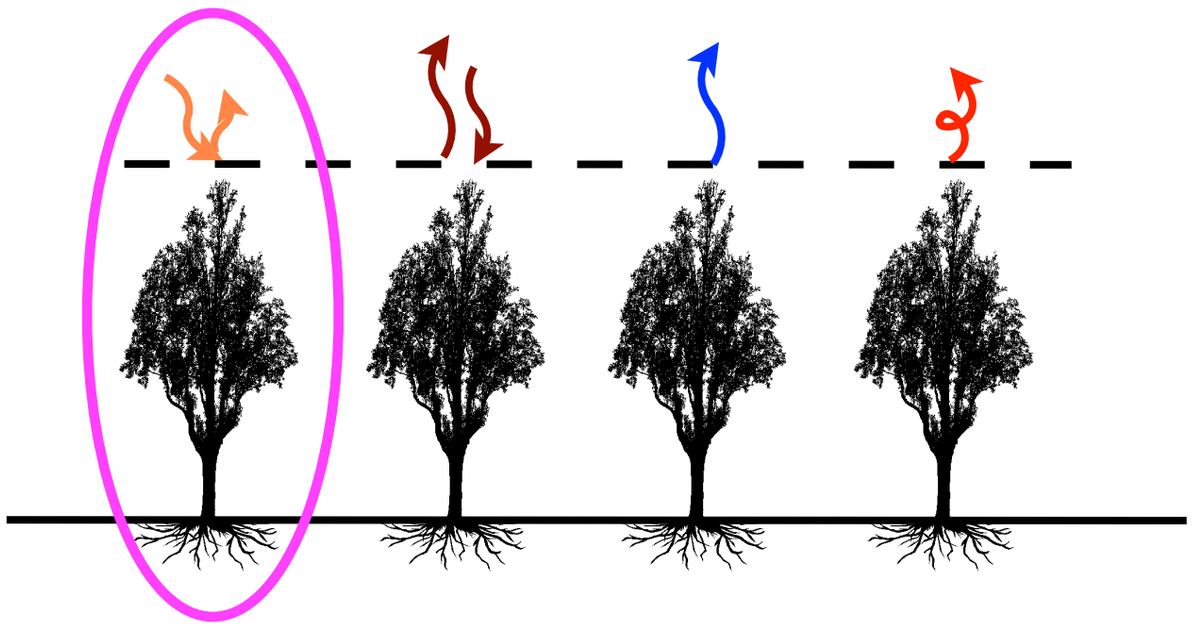
1. Changing Arctic Plant cover and types?
2. Land surface properties globally

Influence of plants on climate varies by latitude

High Latitudes

Albedo dominates

(e.g. Bonan et al. 1992)

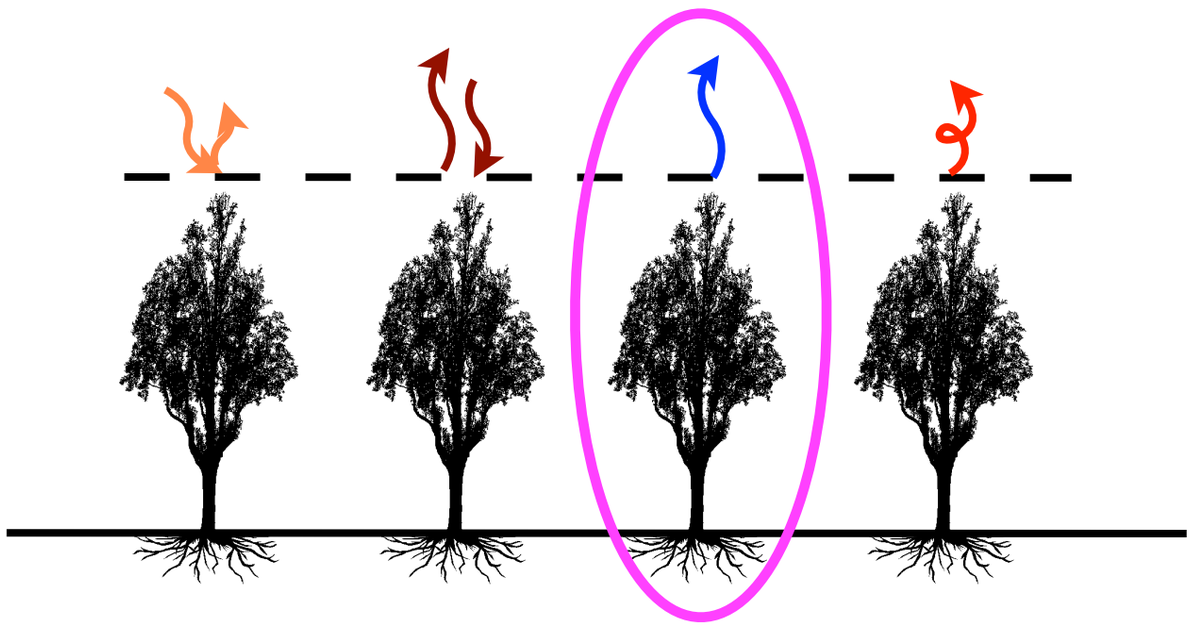


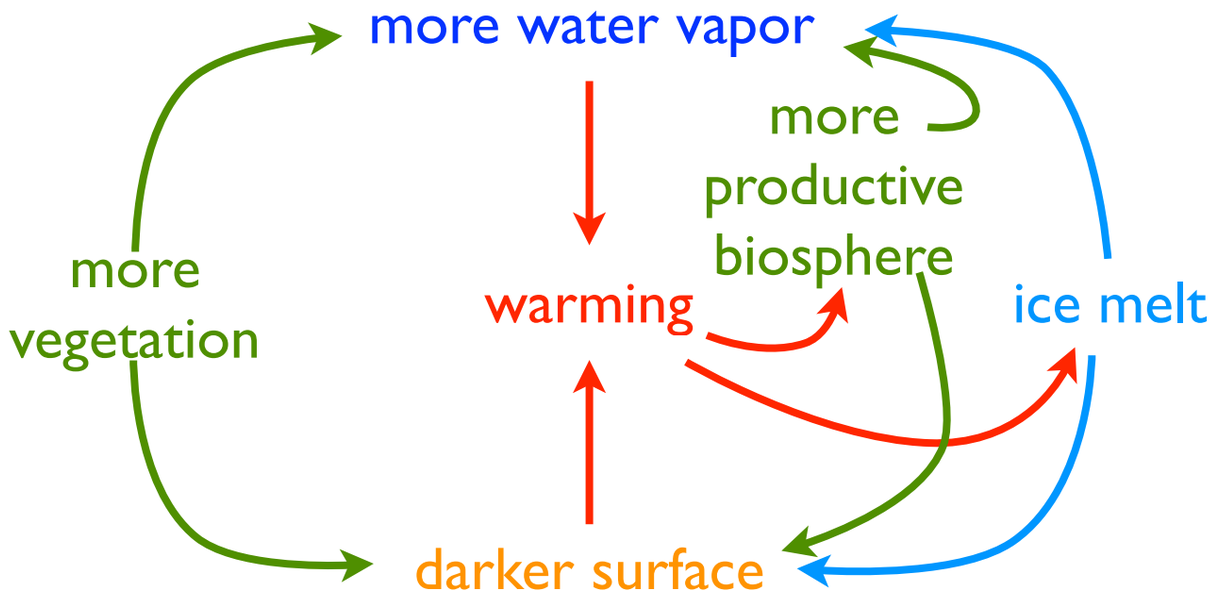
Influence of plants on climate varies by latitude

High Latitudes

Albedo dominates
(e.g. Bonan et al. 1992)

LH influence through greenhouse effect
(Swann et al. 2010)





Quantifying the role that terrestrial ecosystems play in Earth's climate

1. Changing Arctic Plant cover and types?

Darker albedo => warming

Higher latent heat flux => *also* warming

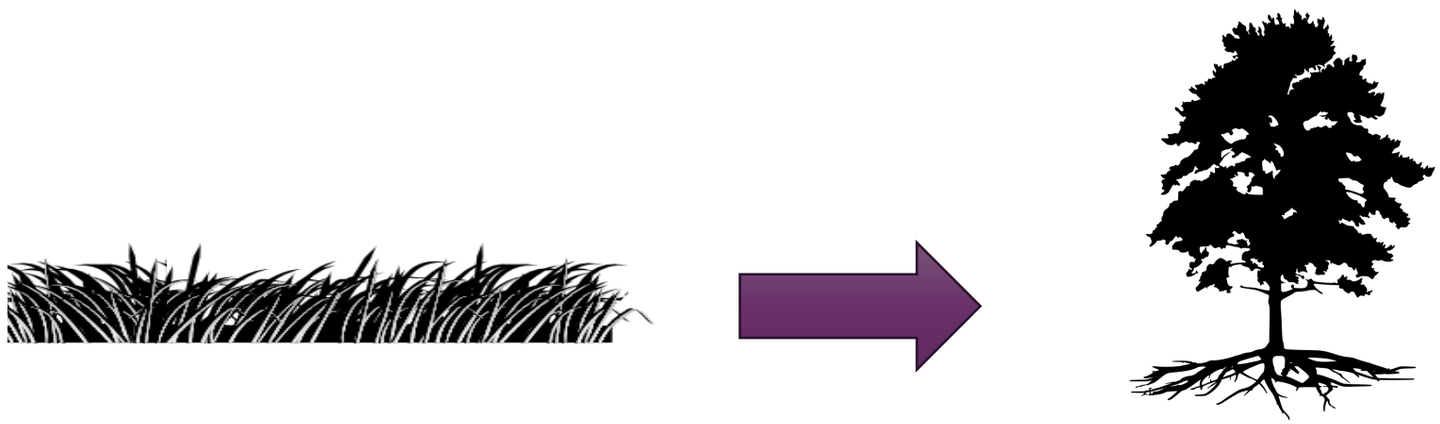
Plus feedbacks from sea ice

Quantifying the role that terrestrial ecosystems play in Earth's climate

1. Changing Arctic Plant cover and types?
2. Land surface properties globally

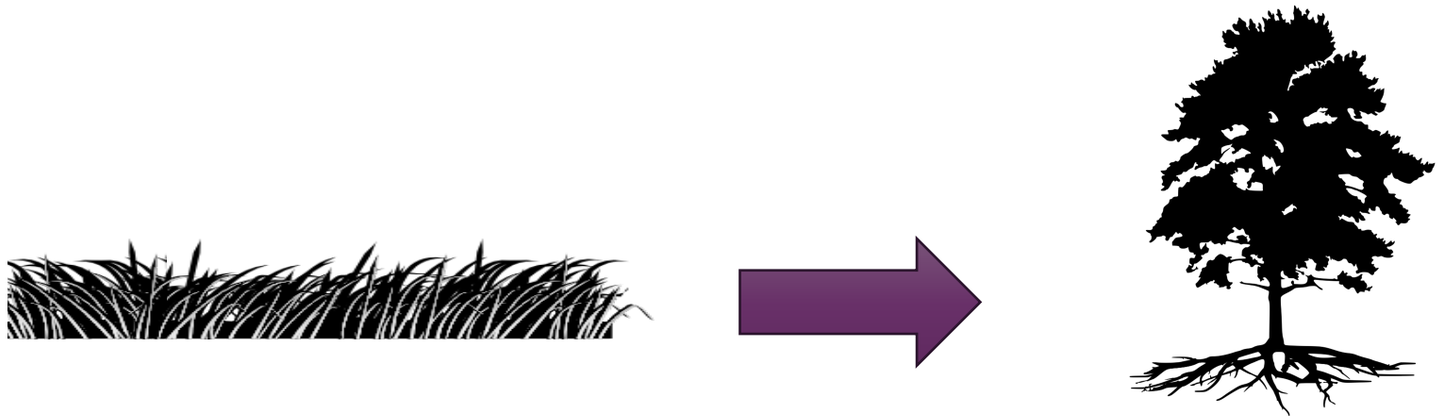
What really is the climate response to changing trees?

(And ***why?***)



What really is the climate response to changing trees? (And ***why?***)

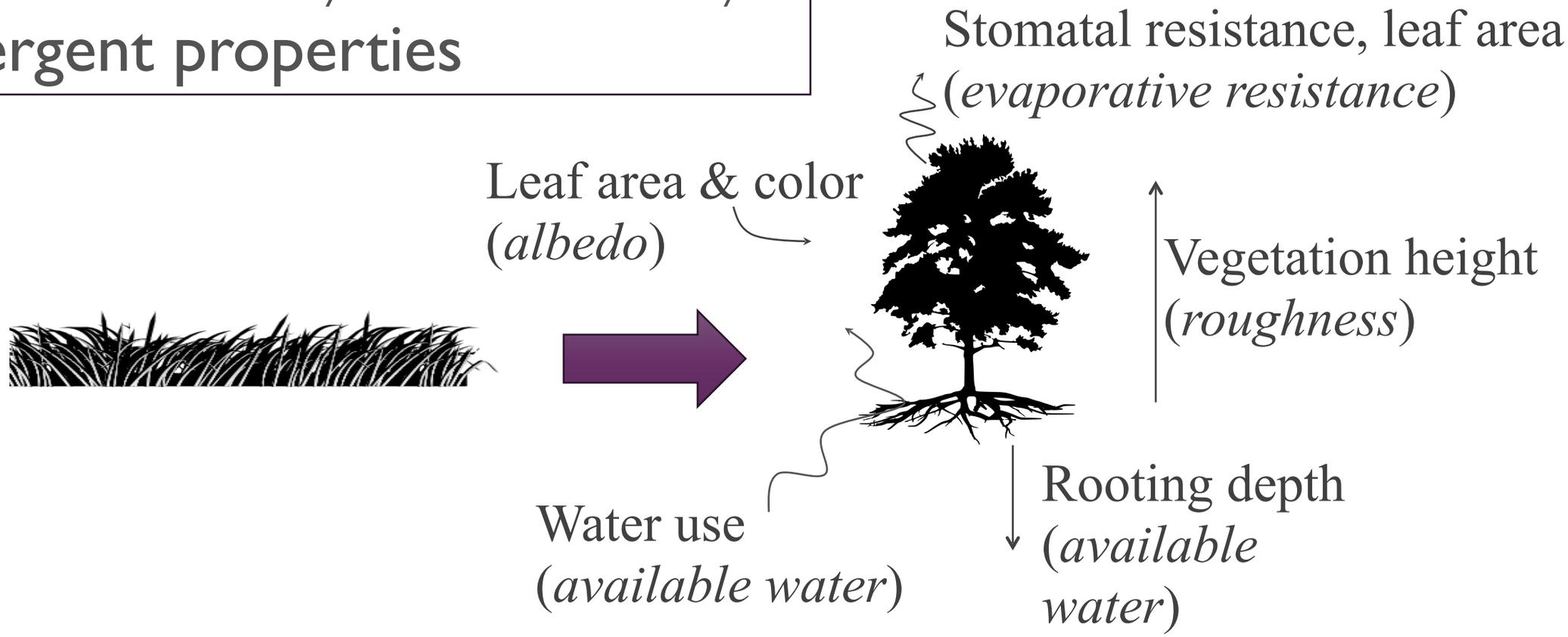
Ideally we could change ***one*** aspect at a time to isolate the effect



What really is the climate response to changing trees?

(And ***why?***)

Grass=>Tree changes **many** aspects
Can't test individually, because many are **emergent properties**



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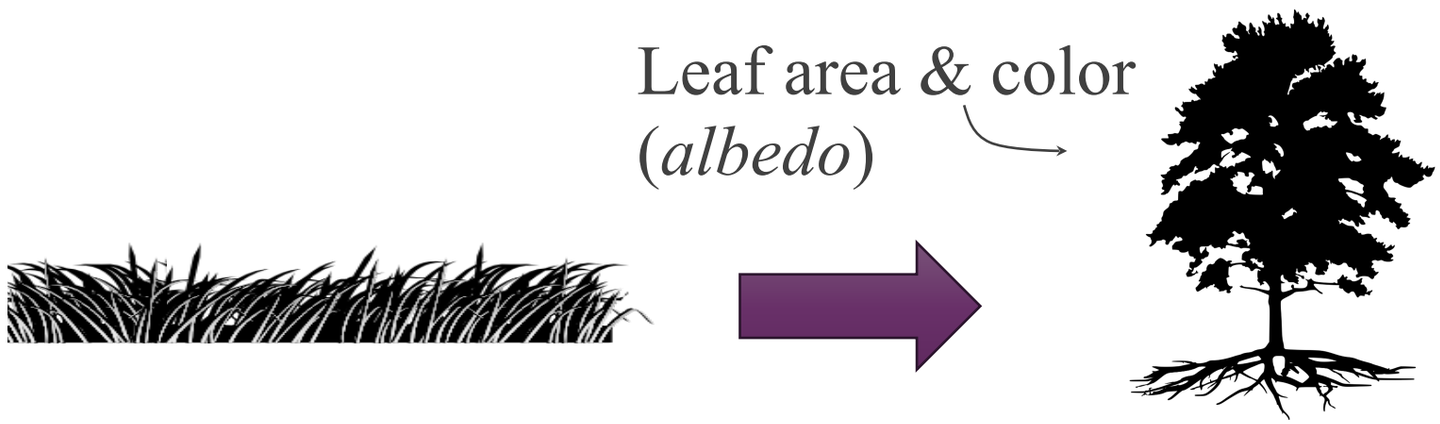


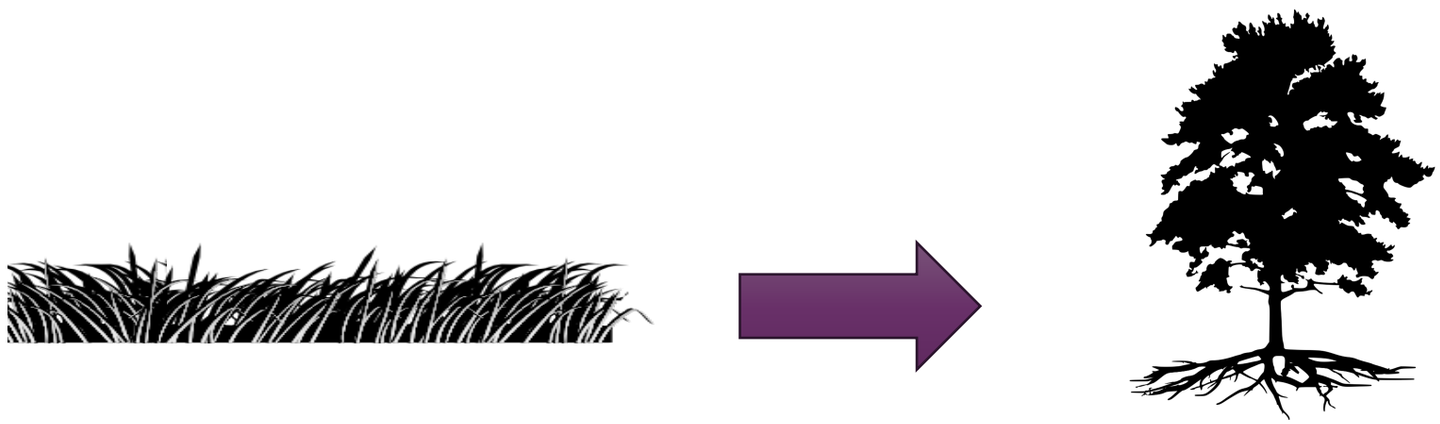
e.g. albedo is not set in most climate models.
It is **calculated**.

albedo = *f*(leaf area, leaf color, soil color, leaf angle, time)

What really is the climate response to changing trees?

(And ***why?***)

It turns out this is a hard question to answer using a complex land model!

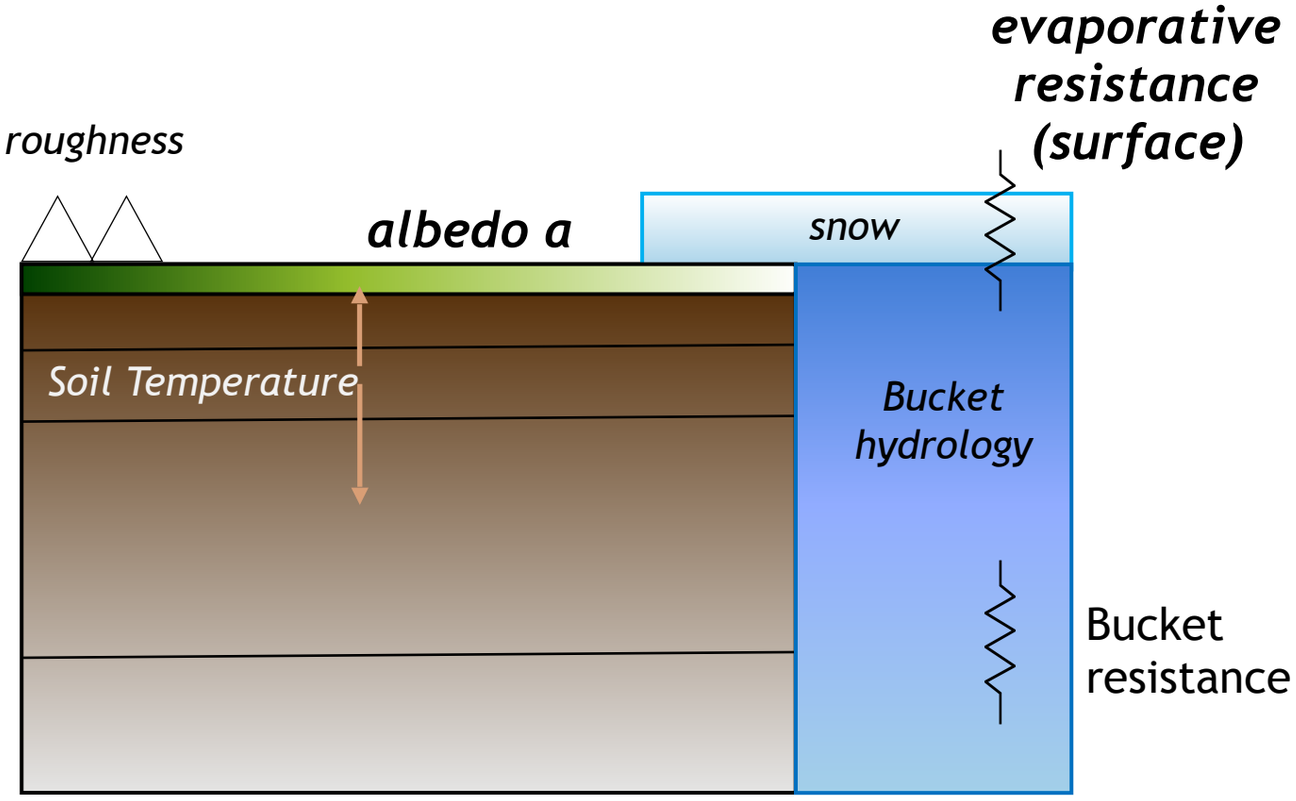


What really is the climate response to changing trees? And ***why***?

=> We built a *very simple* land model to test how the atmosphere responds to changes in the surface

Coupled to CESM in place of the typical land model

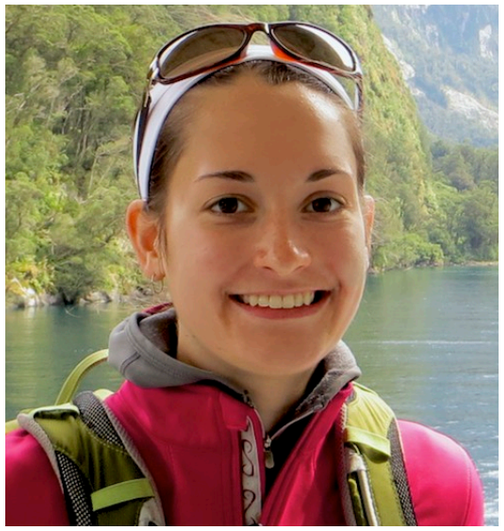
Kind of like an aquaplanet for land…



Looks a lot like Manabe (1969); draws from LM2 (land portion of GFDL's AM2LM2 model),
LSM1 (1996 NCAR model)

Work with Marysa Laguë & Gordon Bonan

What really is the climate response to changing trees? And ***why***?



Marysa Laguë

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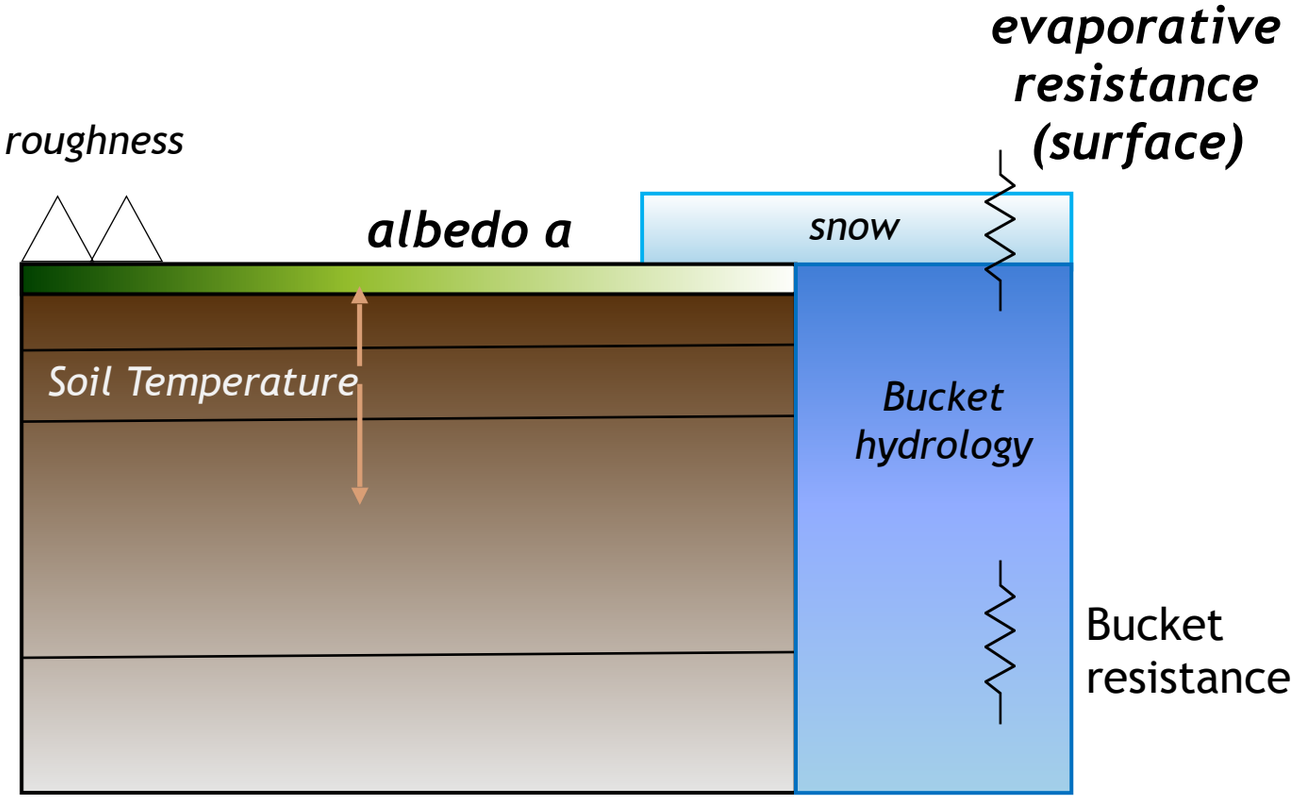

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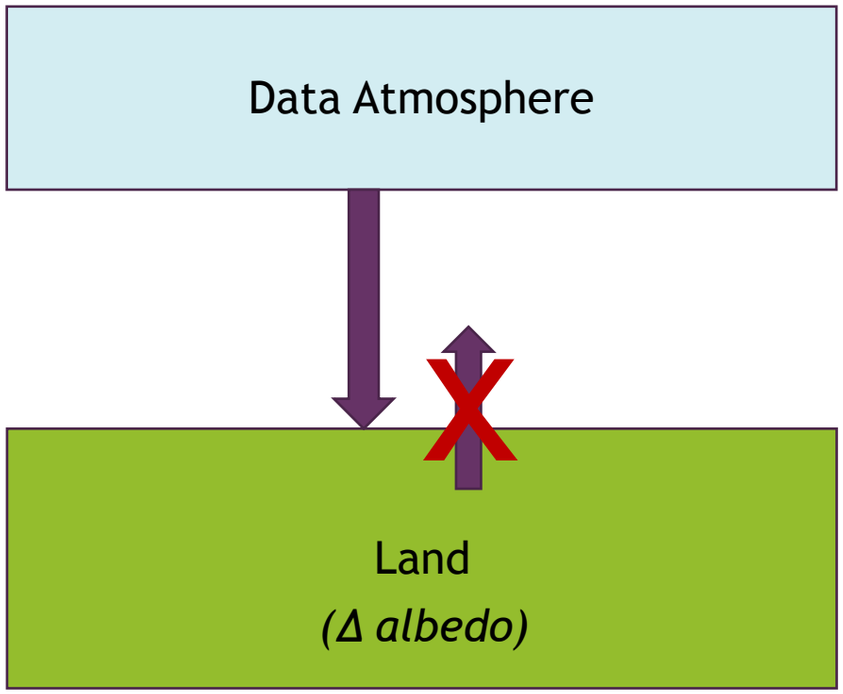
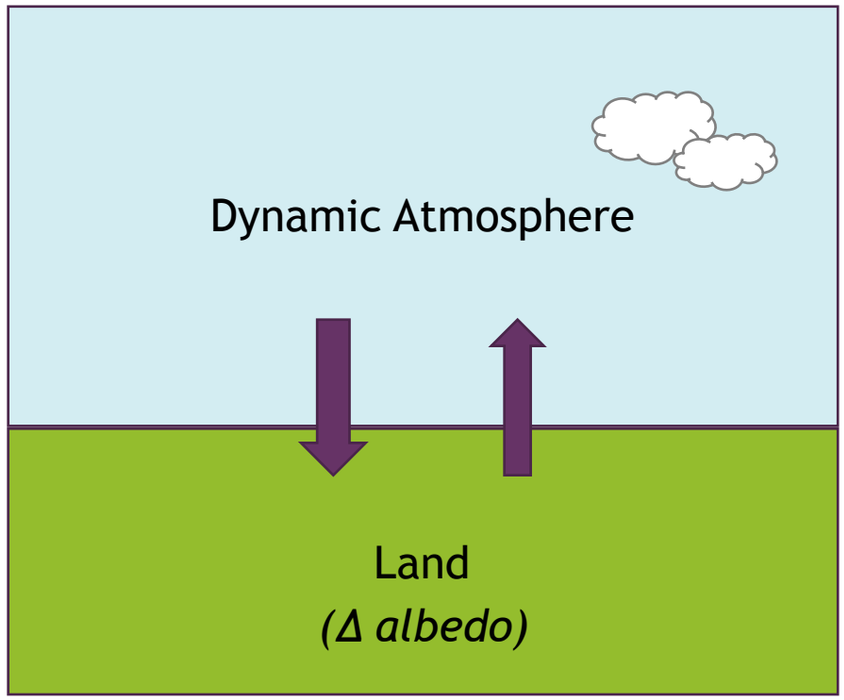
Two parts of the total climate response to a surface property change:

Land-only (**forced** response)



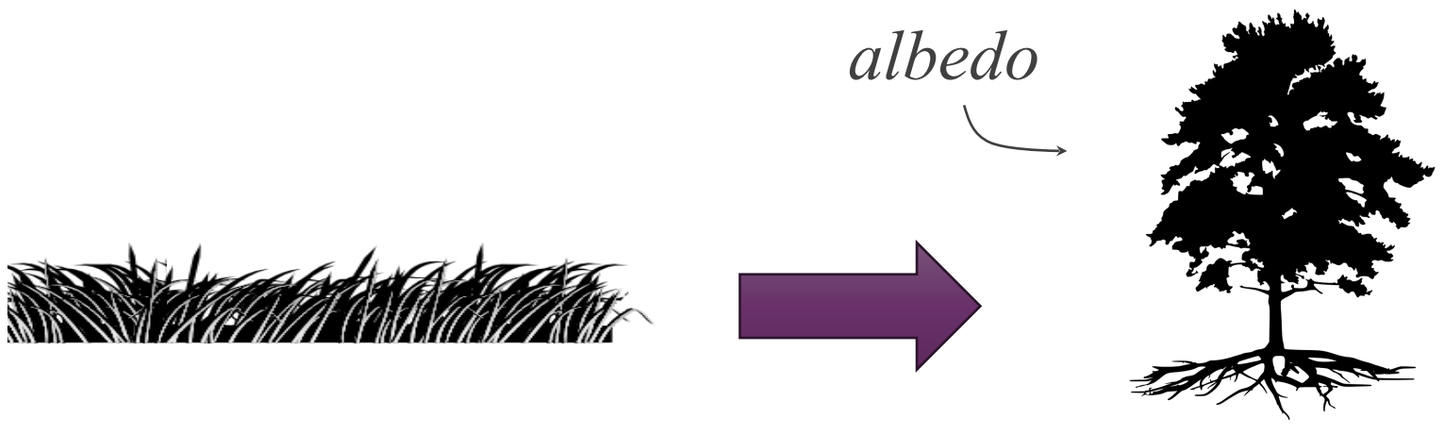
Changes in the surface energy budget uncoupled from the atmosphere

Coupled
(Forcing + **Feedbacks**)



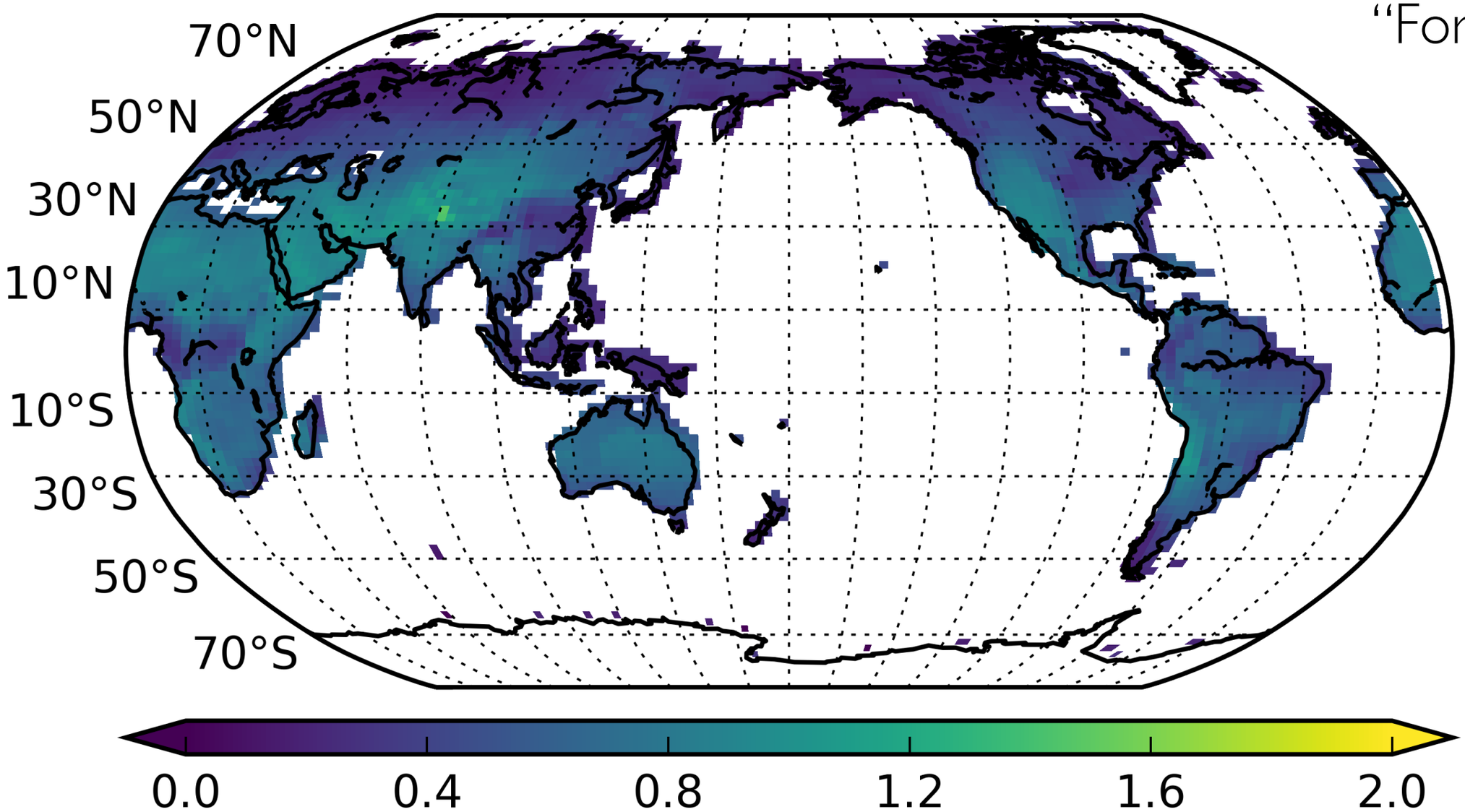
Changes in the surface energy budget that include feedbacks from the atmosphere

What is the climate response to changing ***albedo***?

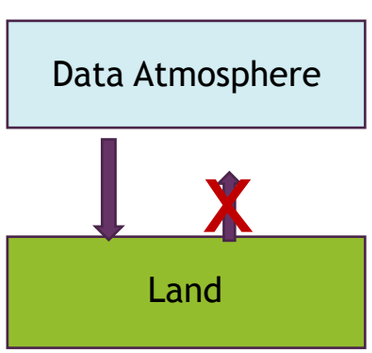


Temperature response to a change in surface albedo of 0.1

Land only
"Forcing"



$\delta T_s[K]/\delta 0.1\alpha$



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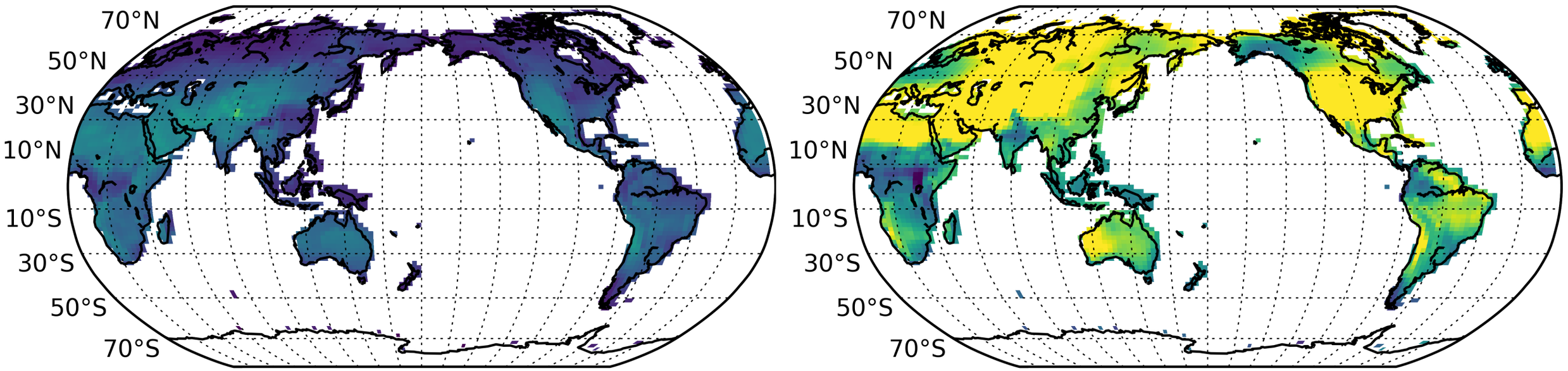
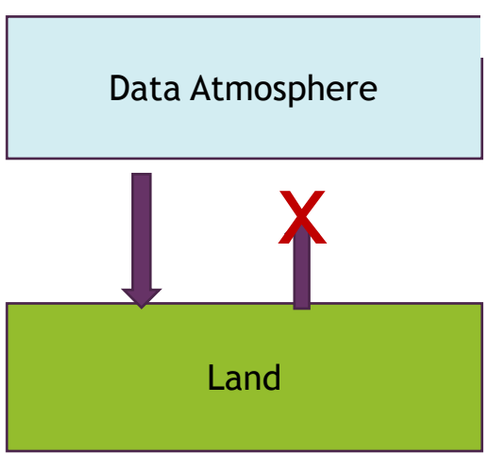
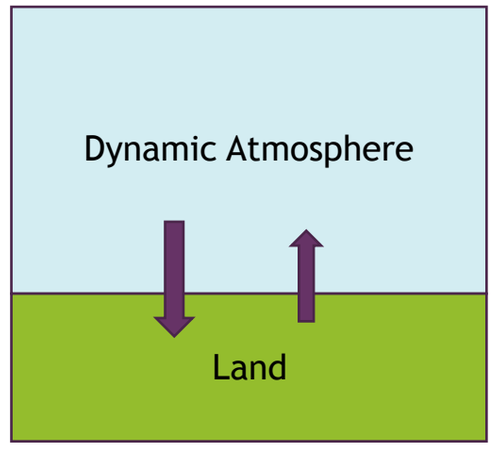
Feedback from the atmosphere is large!

Land only
"Forcing"

Land + Atmosphere
"Forcing + Feedback"







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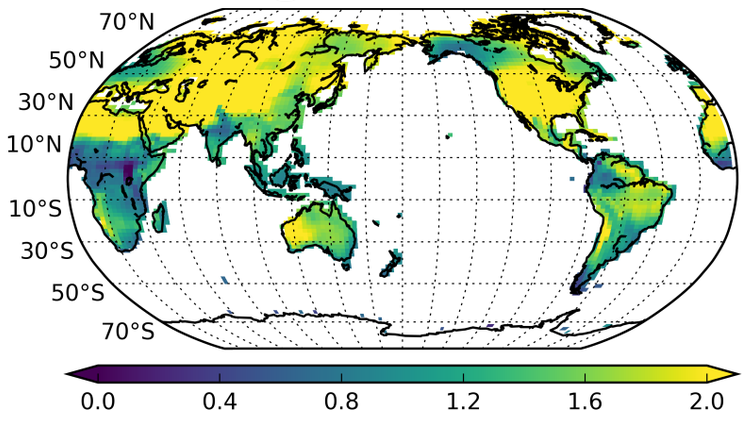
We can quantify the feedback from the atmosphere

Feedback
(Warming due to atmosphere)

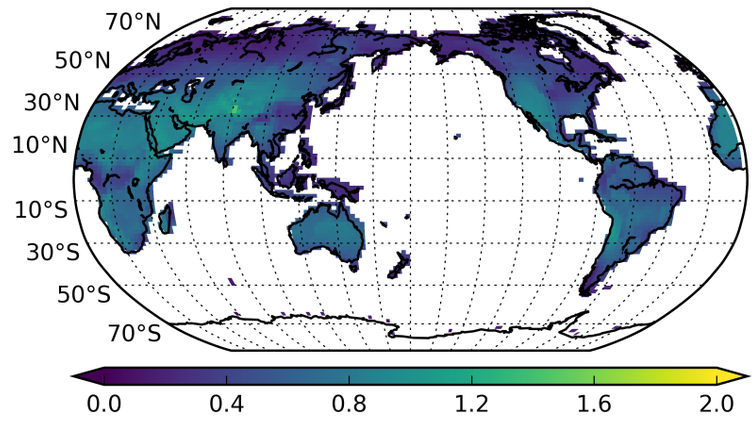
=

Land + Atmosphere
"Forcing + Feedback"



-

Land only
"Forcing"



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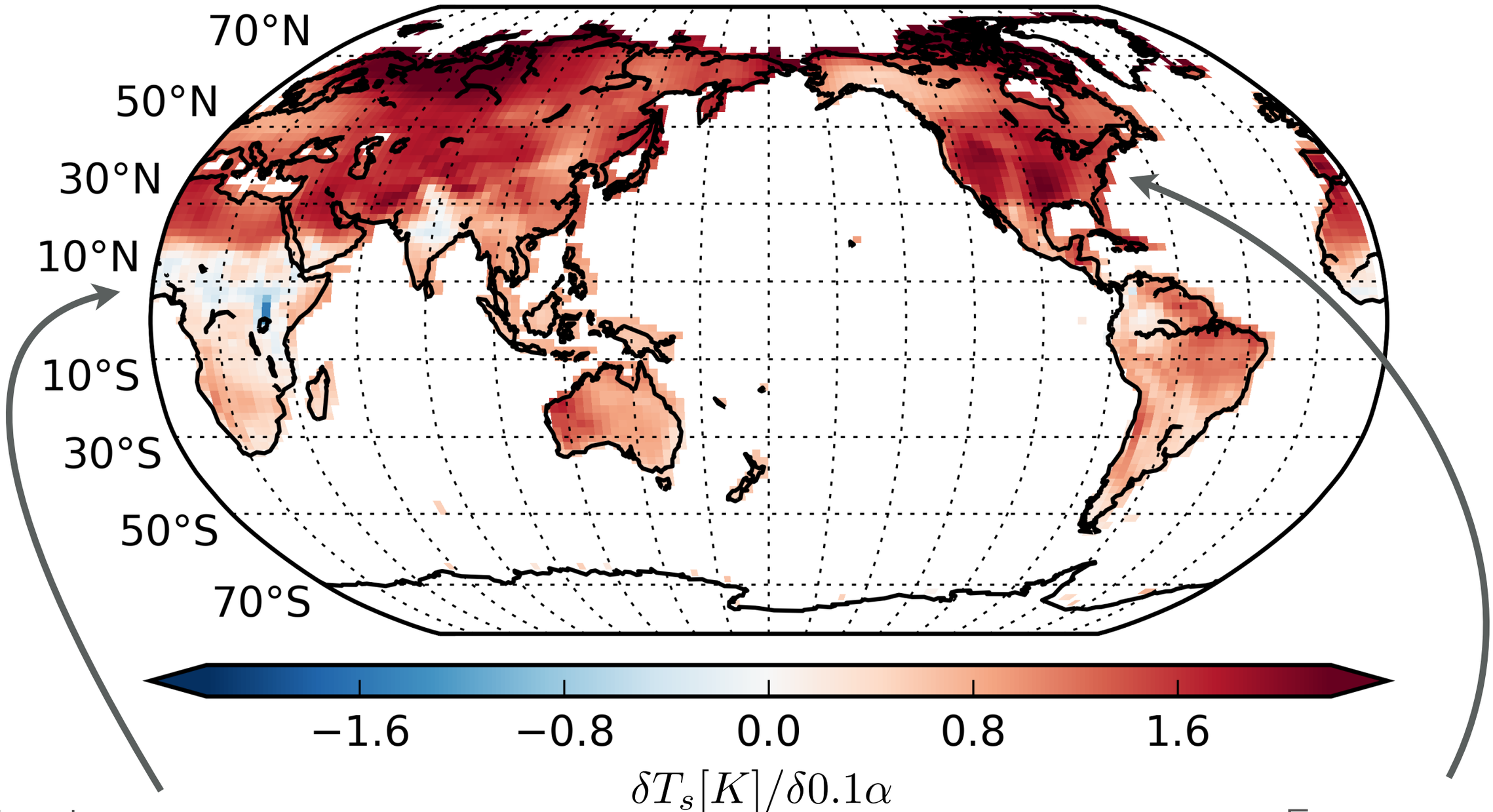
We can quantify the feedback from the atmosphere



Tropics:
get most of the answer
from the surface

Extra-tropics:
lots of warming from
atmospheric feedbacks

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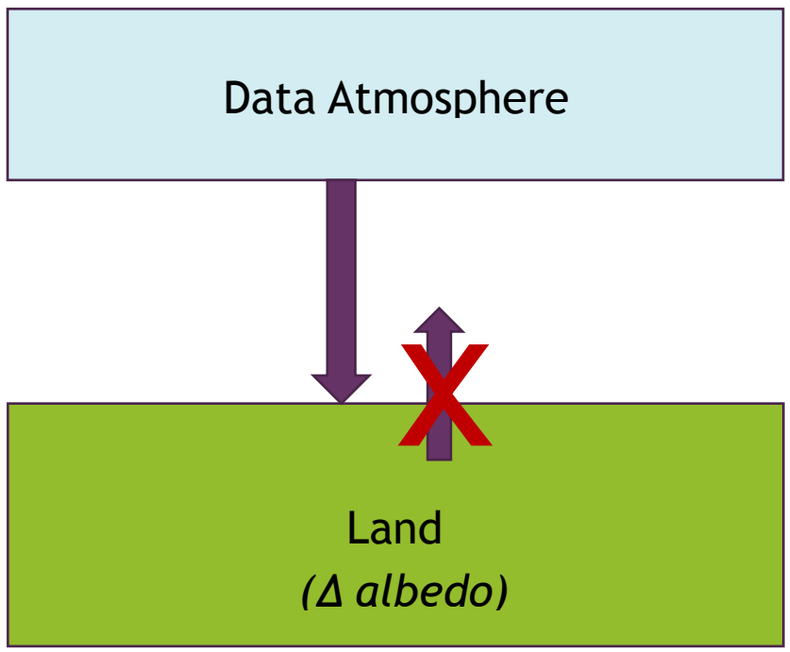
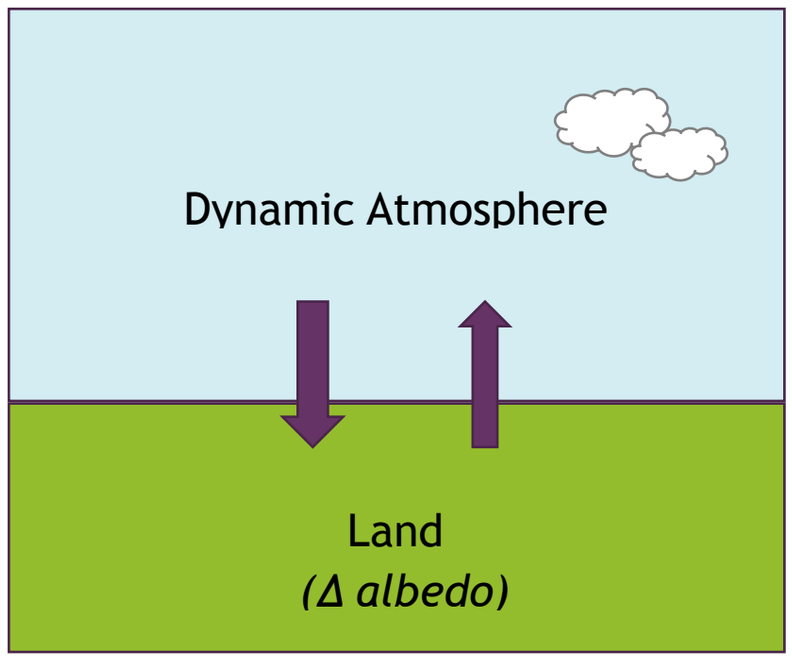
Feedback from the atmosphere can be both *local* and *remote*

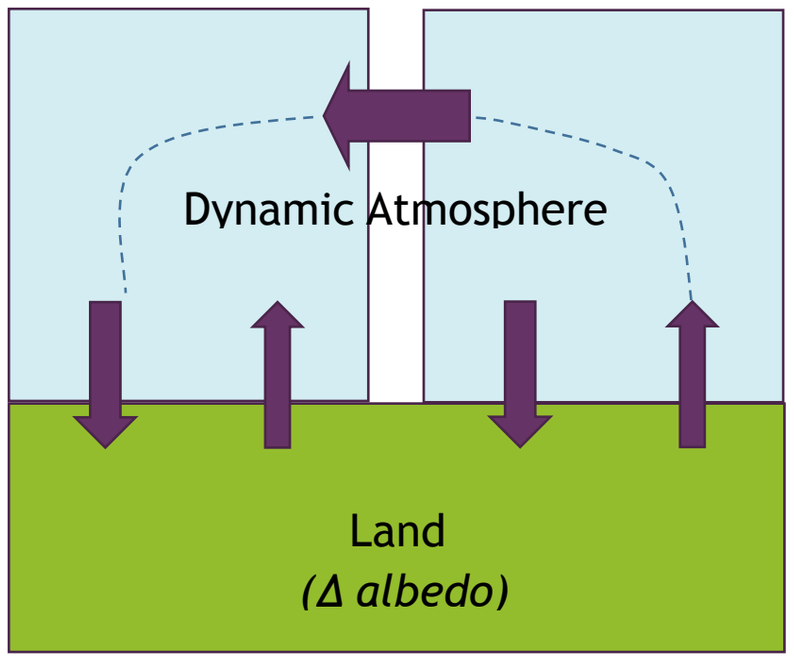
Land-only (**forced** response)



Local Atmospheric **Feedback**



Remote Atmospheric **Feedback**



=> we have to find a way to separate local and remote feedbacks

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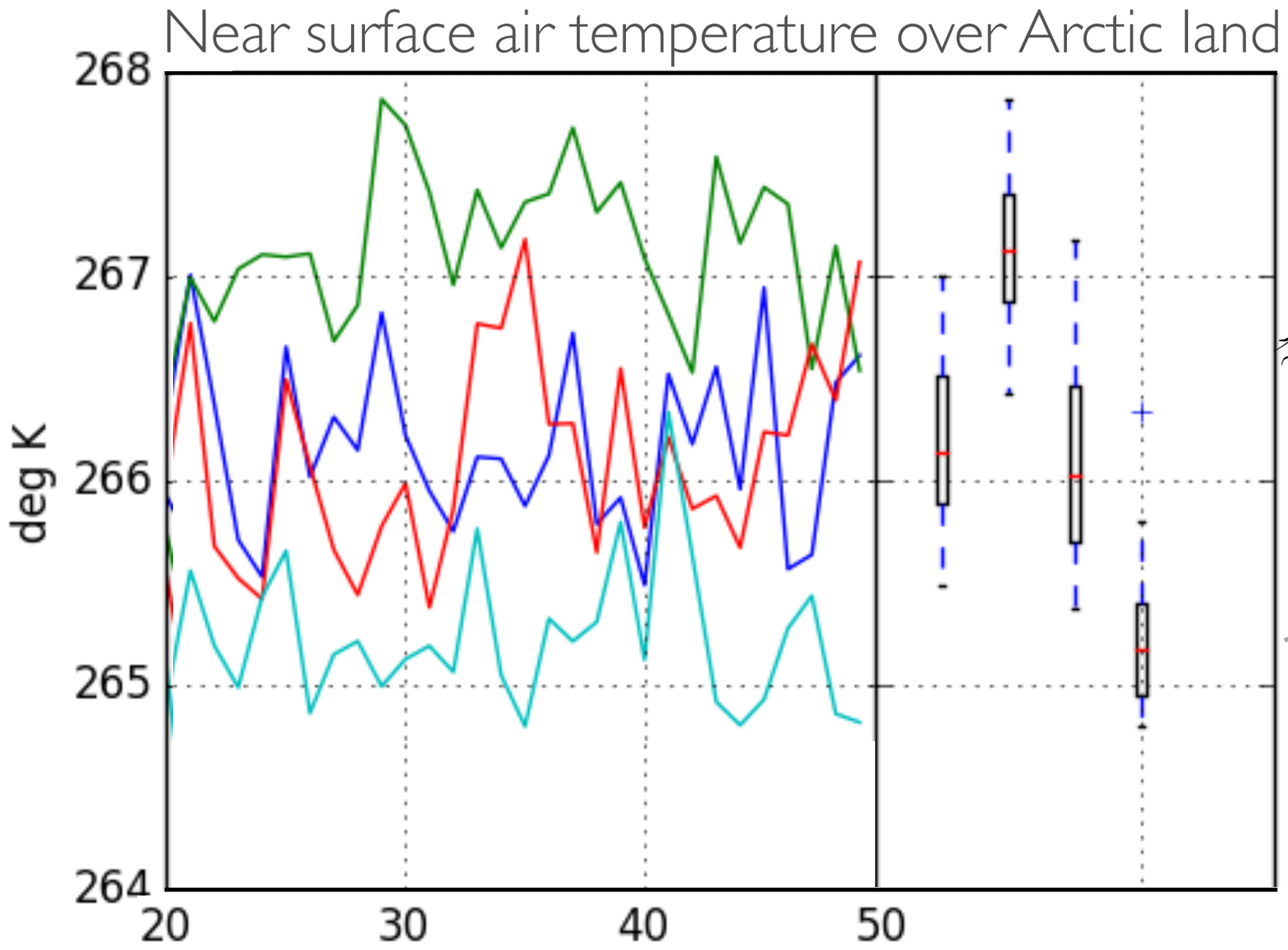
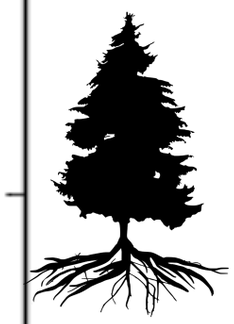
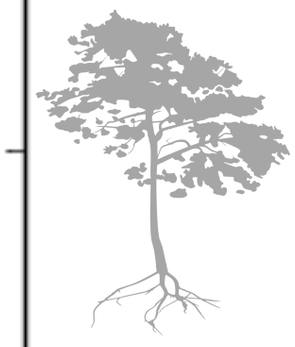
Albedo & Evapotranspiration varies by plant type

Needleleaf has warmer surface, but: Δtemperature from Δalbedo = Δresistance





Needleleaf:
Dark
Low ET



Broadleaf:
Bright
High ET

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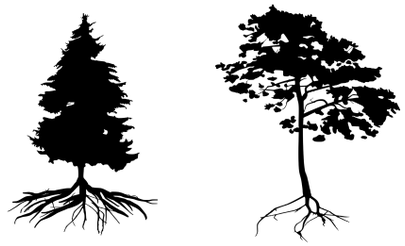
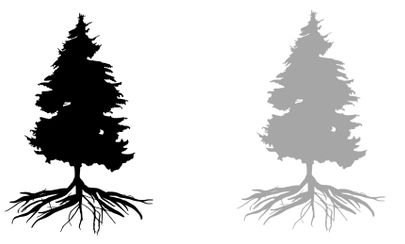
Different spatial pattern of warming from albedo and evap resistance

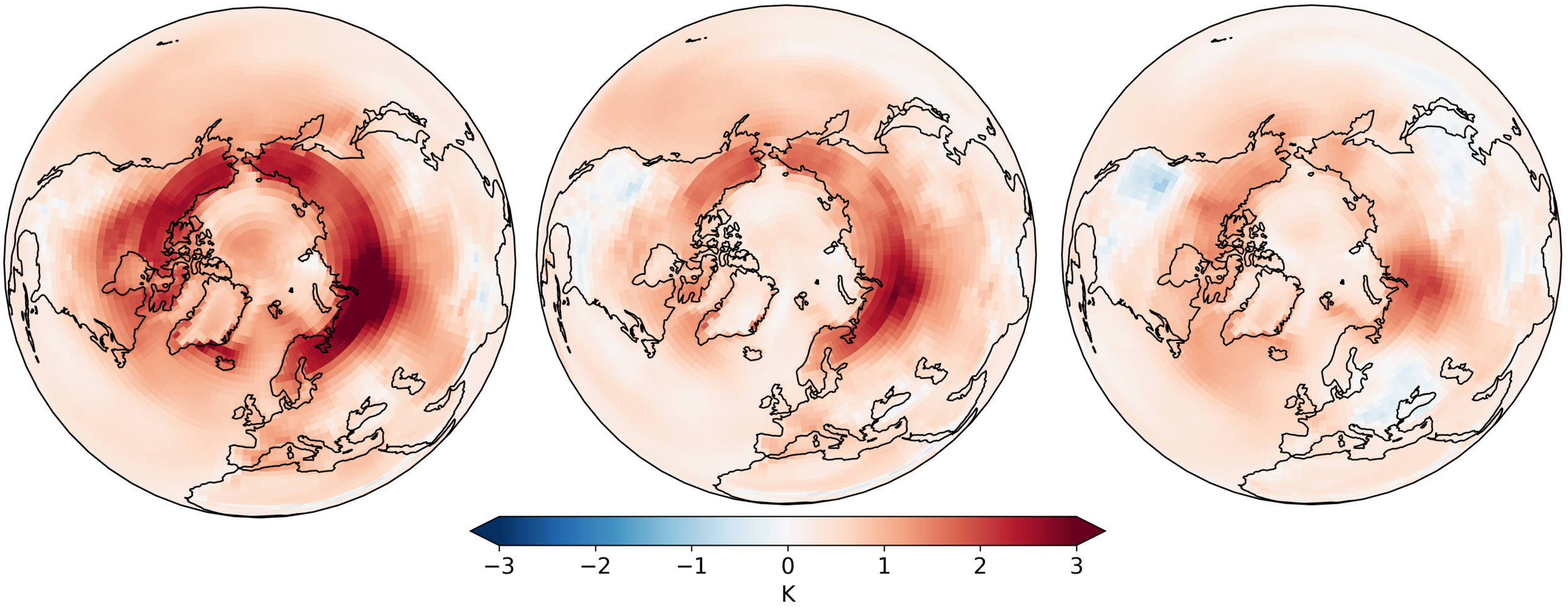
Evap Resistance & Albedo

Evap Resistance



Albedo





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Quantifying the role that terrestrial ecosystems play in Earth's climate

1. Changing Arctic Plant cover and types?
2. Land surface properties globally

Atmospheric Feedbacks are *large*

Albedo is not the only important thing in the Arctic

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