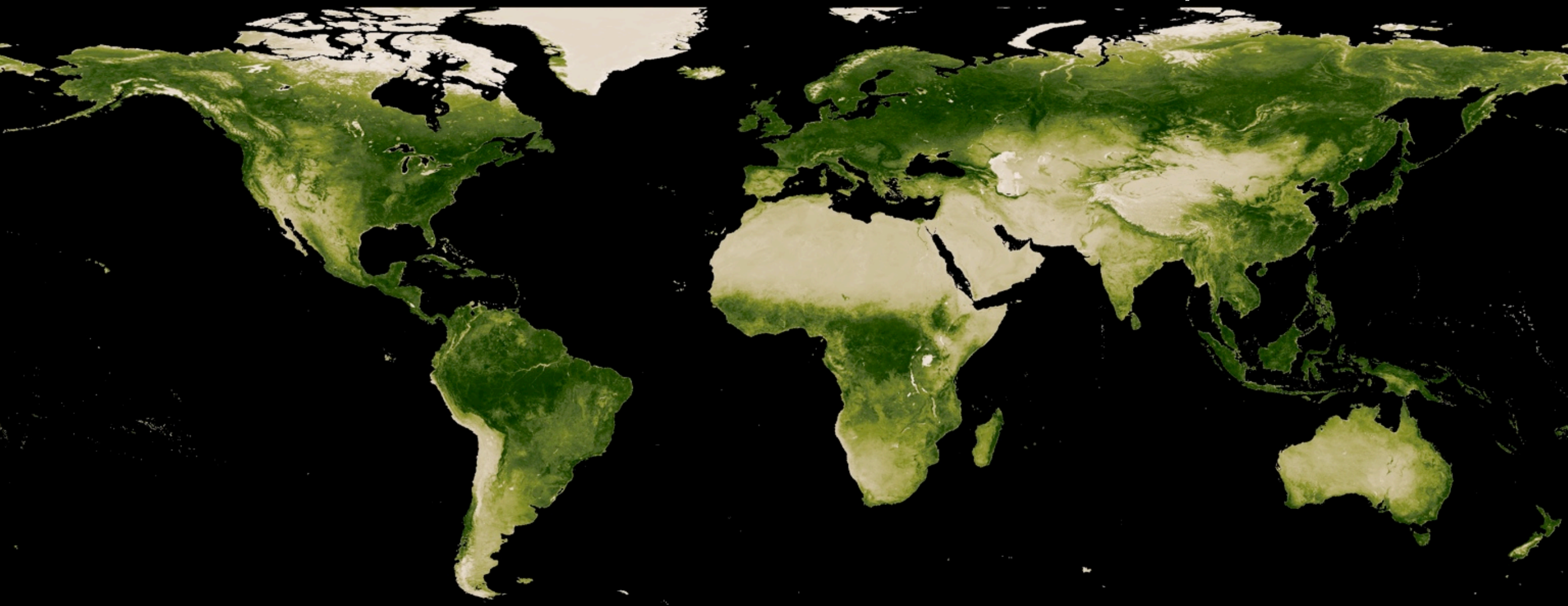
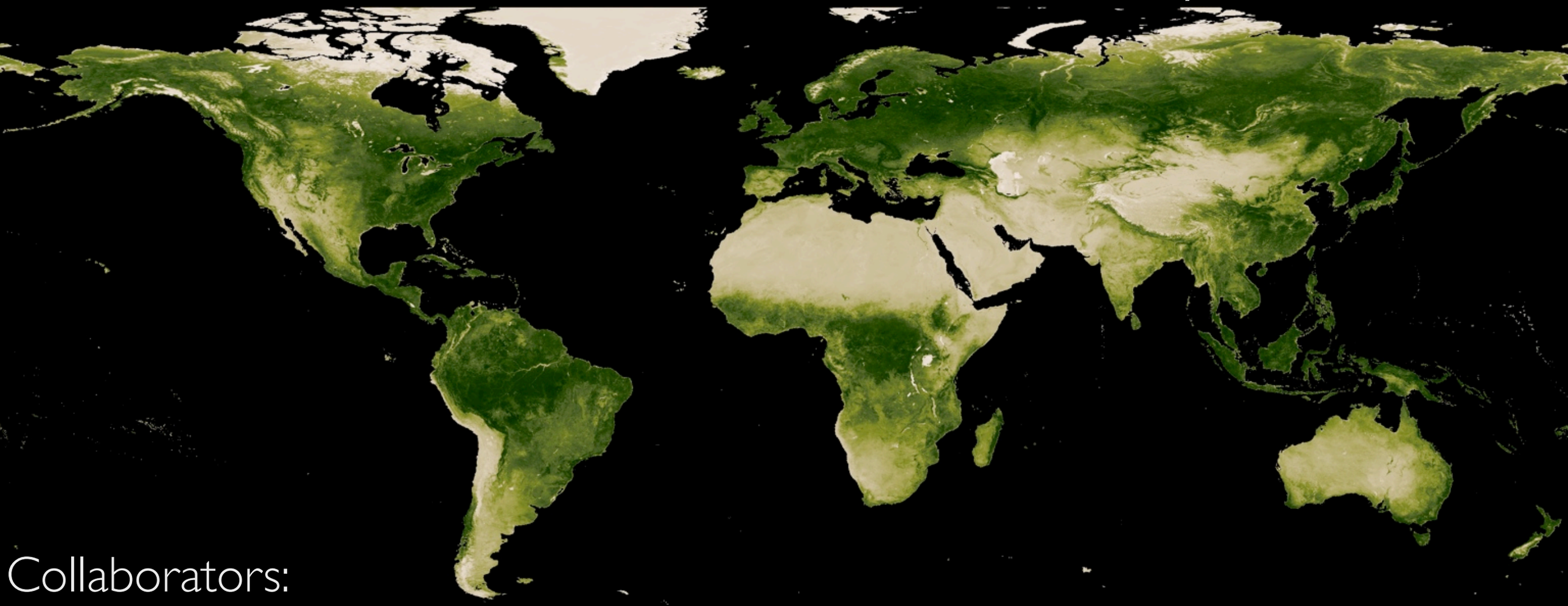
Flexible Complexity as a Tool for Understanding the Role of Land in the Earth System



Abigail L.S. Swann
Department of Atmospheric Sciences
Department of Biology
University of Washington

Flexible Complexity as a Tool for Understanding the Role of Land in the Earth System



Collaborators:
Marysa Laguë, University of Washington
Gordon Bonan, National Center for Atmospheric Research

Abigail L.S. Swann
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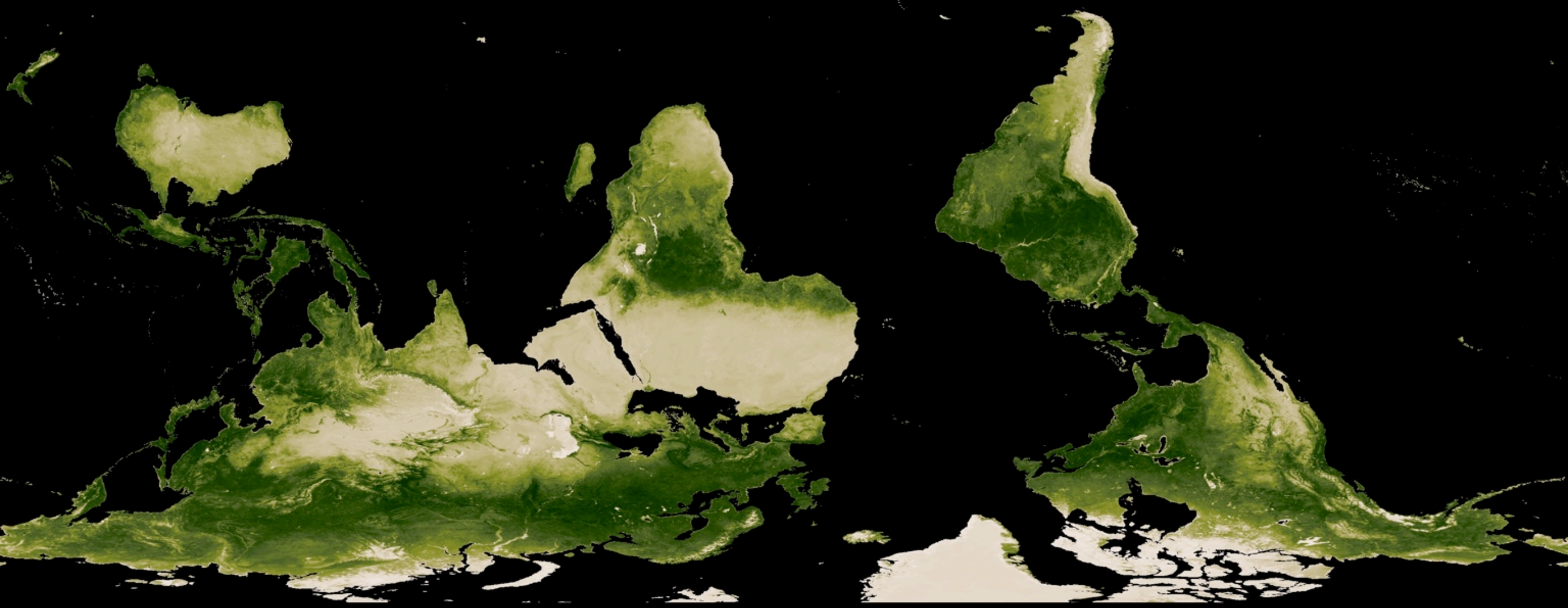
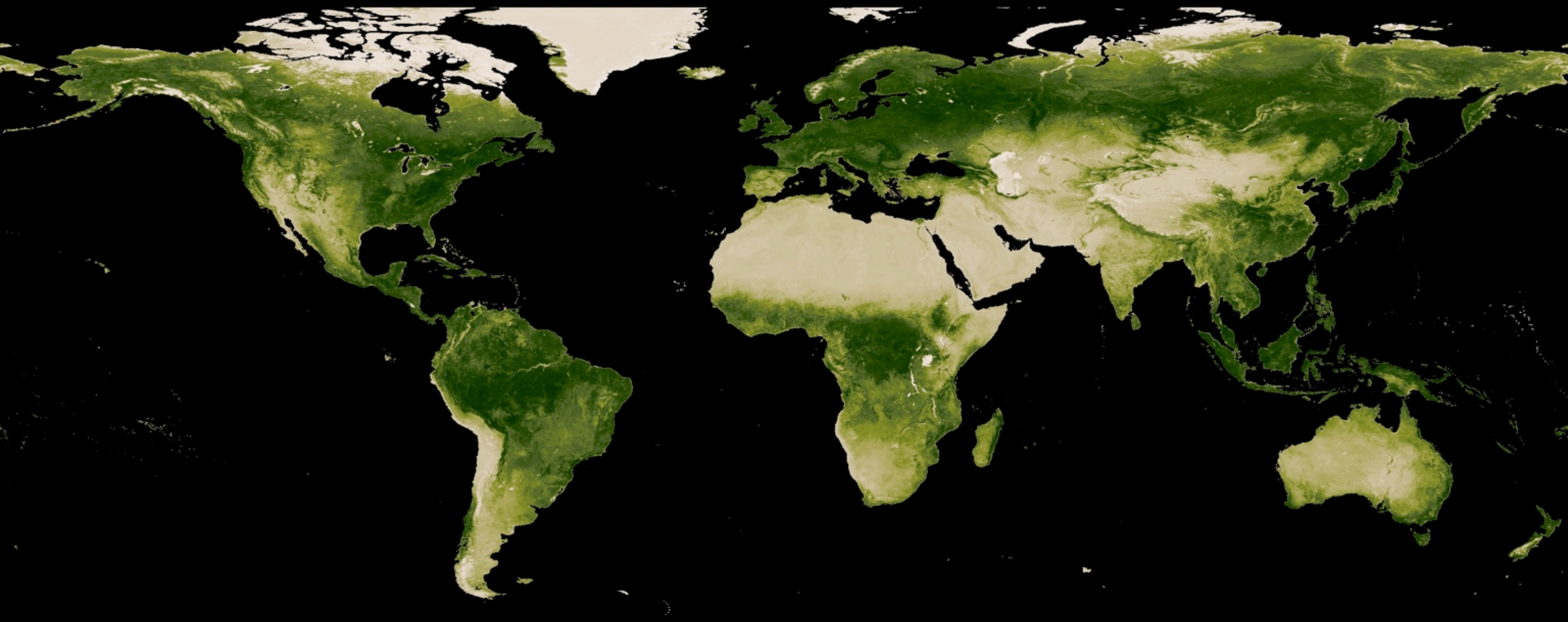
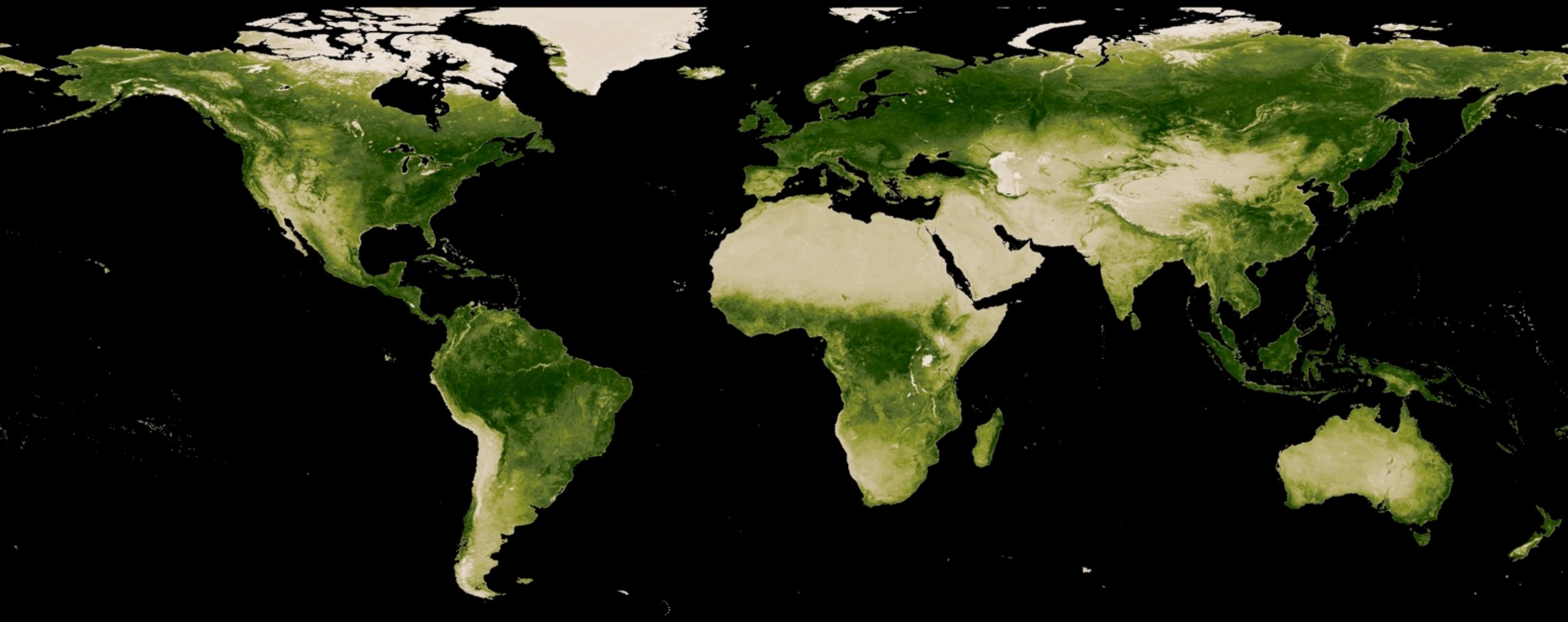
Funding from NSF



Plants ⟷ Climate



Where and *How* do plants influence climate?



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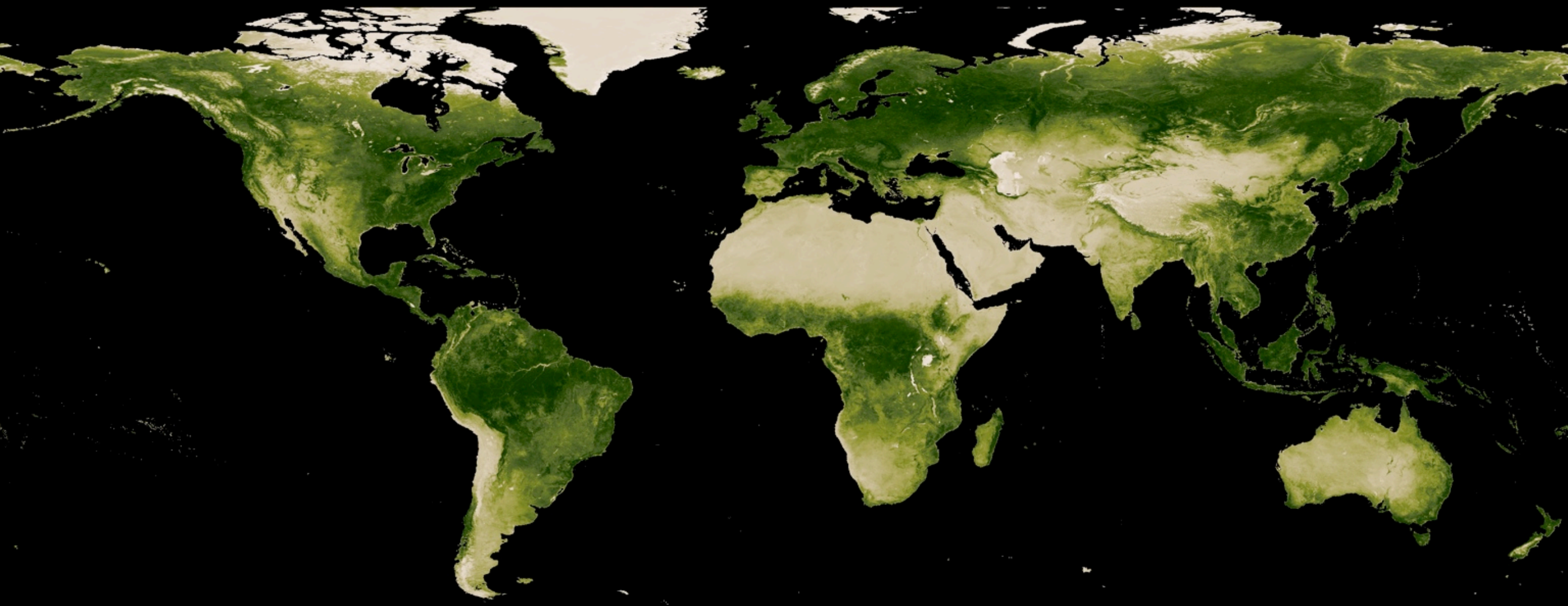


Need to know the response of the atmosphere!

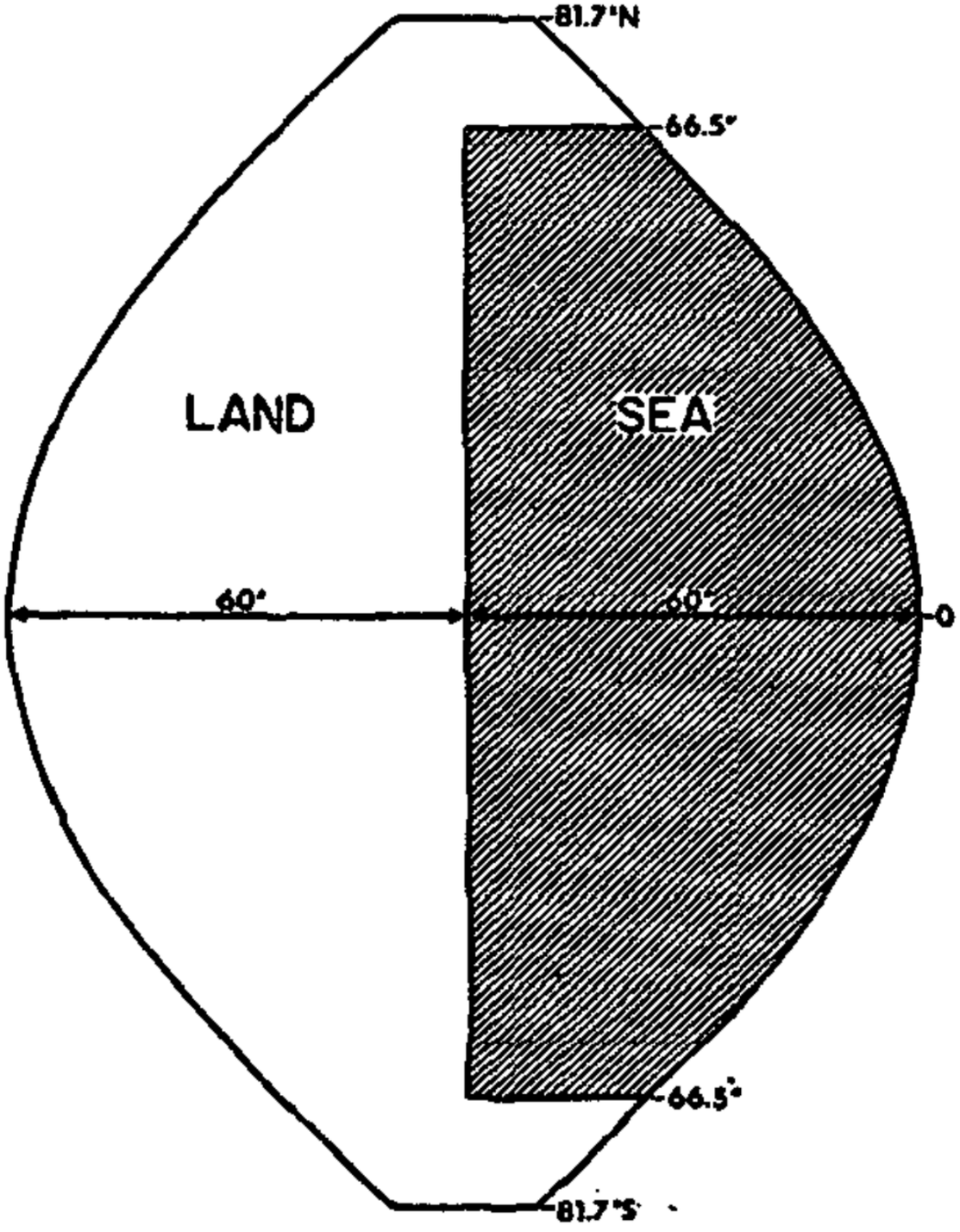
My argument today:

What is the right level of complexity of biosphere and land models in Earth system models?

Simpler models can help us *better understand* interactions between the land and the atmosphere

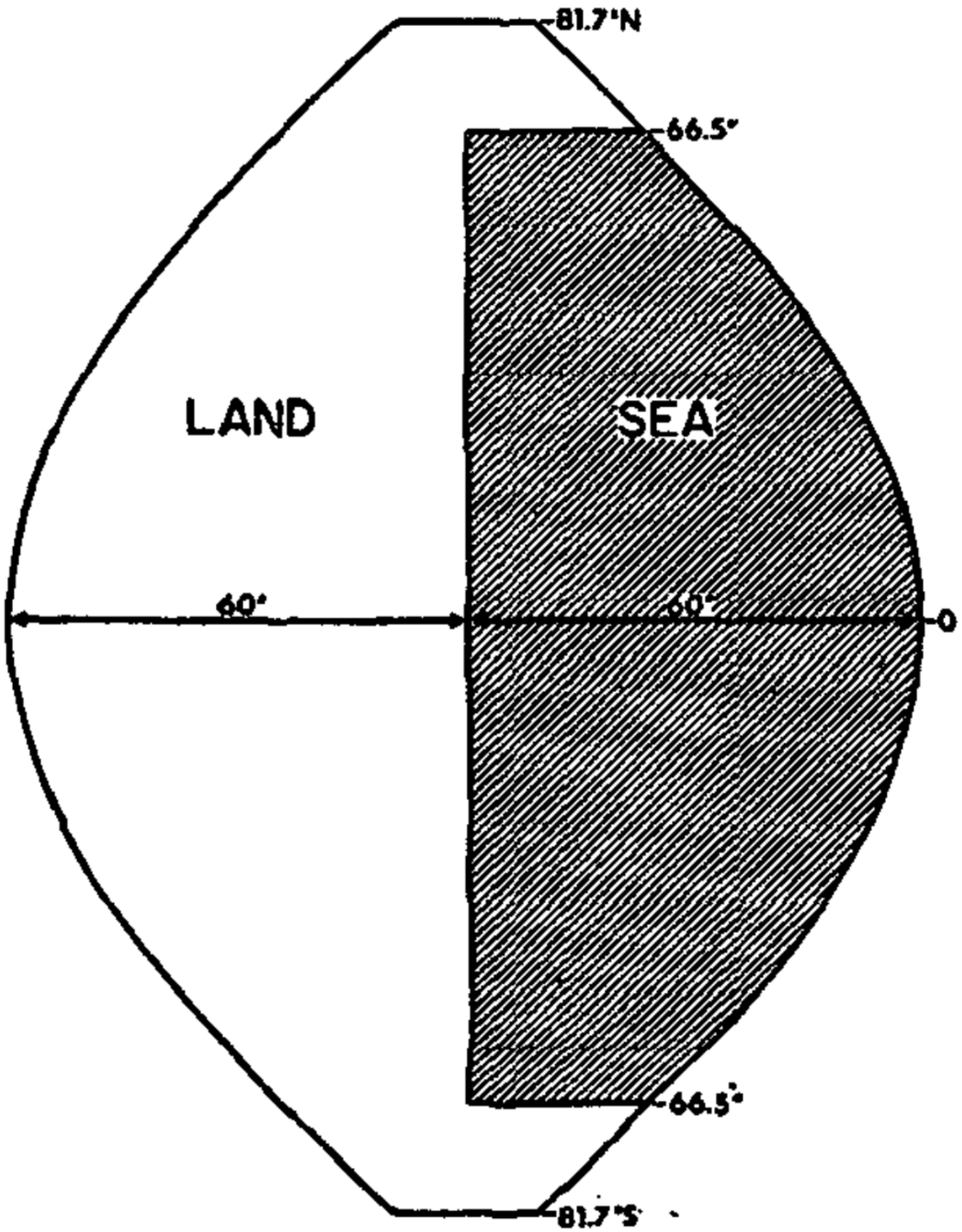
An ideal ESM would have *many options* for land surface complexity that are self-consistent

Representing Land in Earth System Models



Manabe and Bryan 1969

Representing Land in Earth System Models



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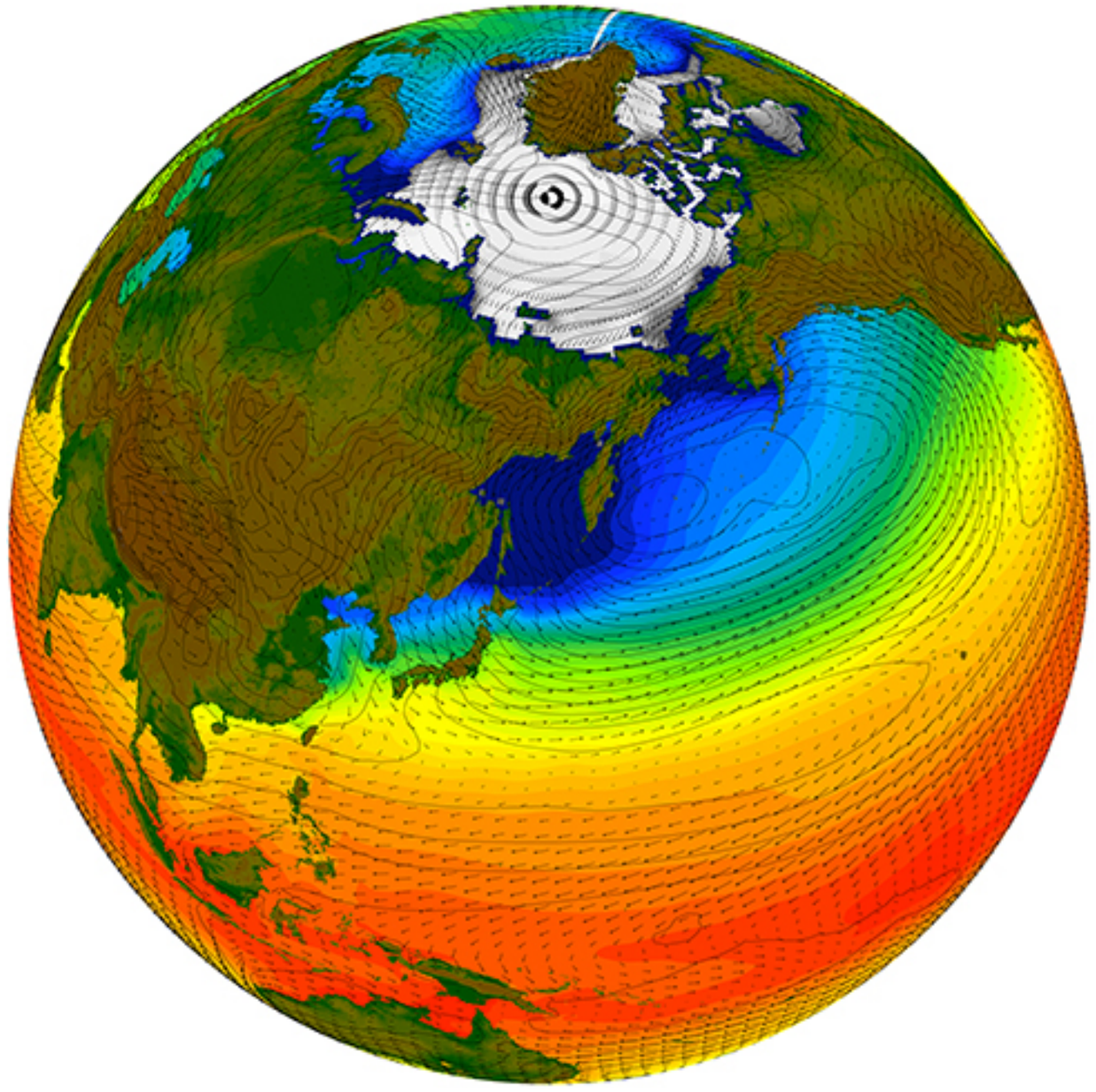
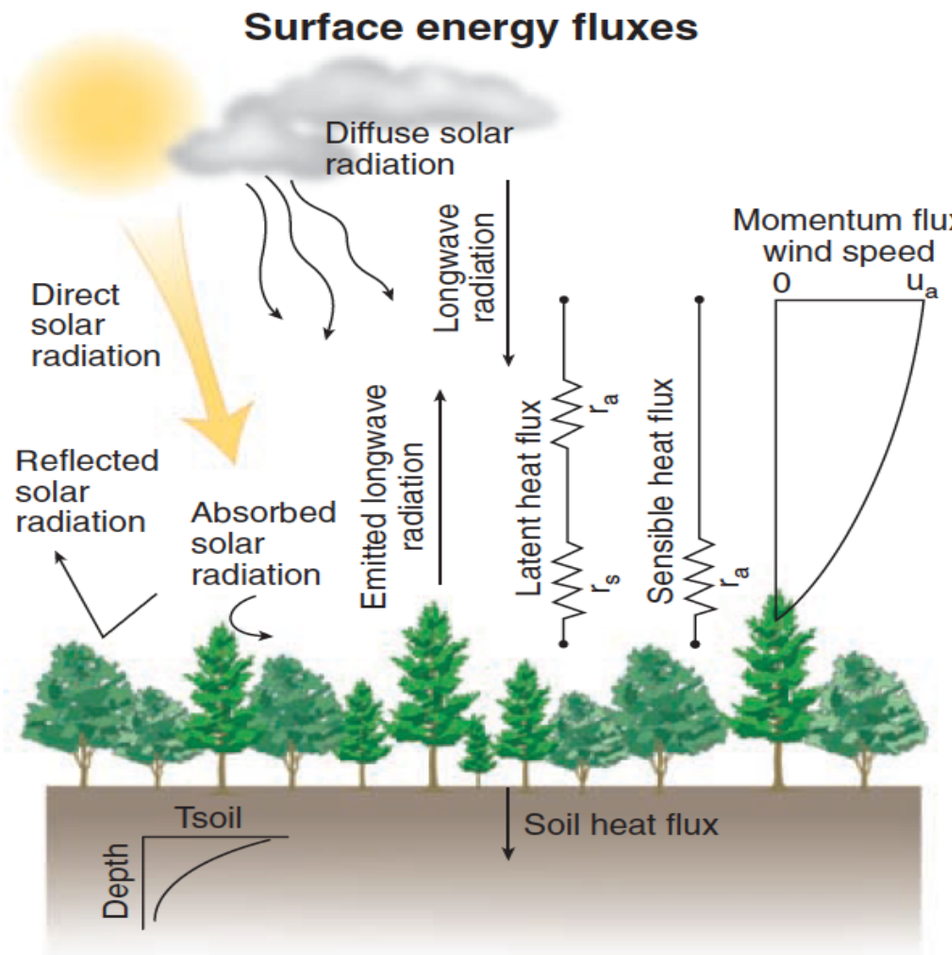
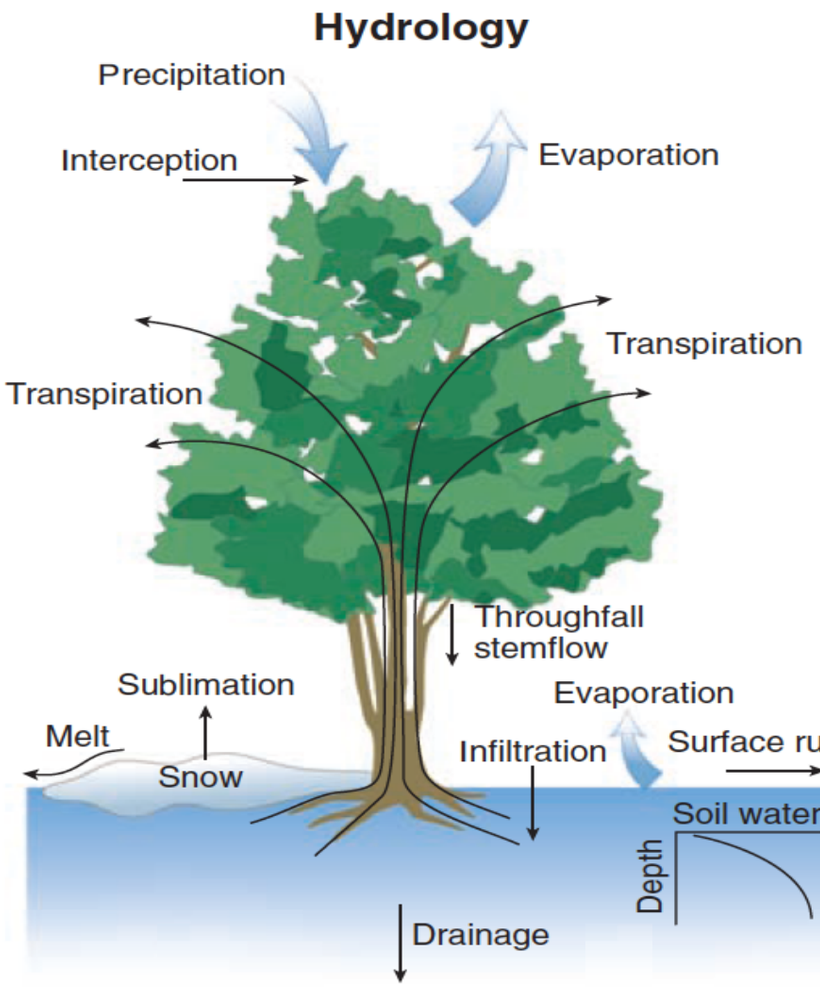
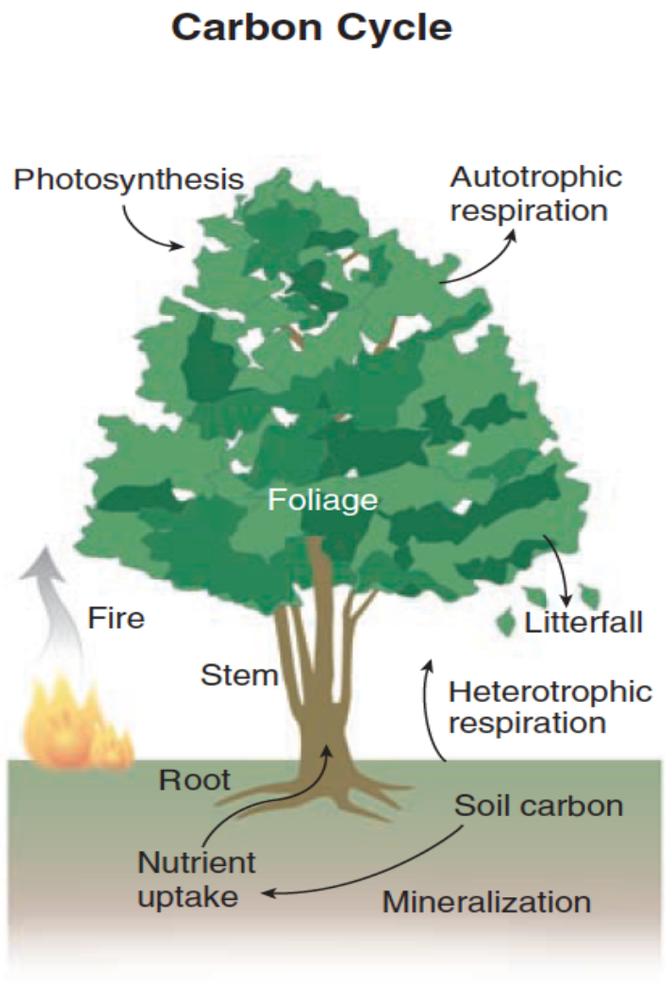


An ESM

Land in Earth System Models



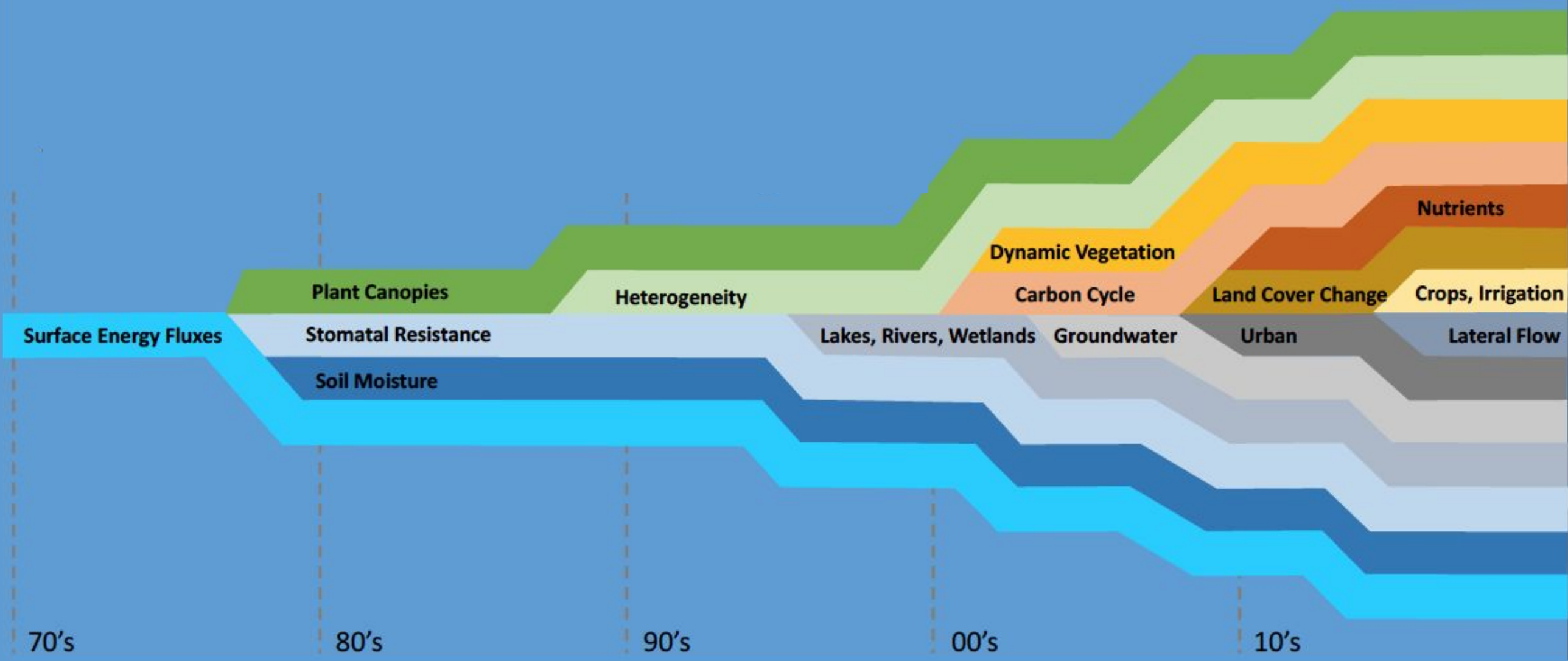




In this case: the Community Earth System Model (CESM)

Bonan 2008

The Evolution of Land Surface Modeling



Rosie Fisher

Do we know the impact of all of this complexity?

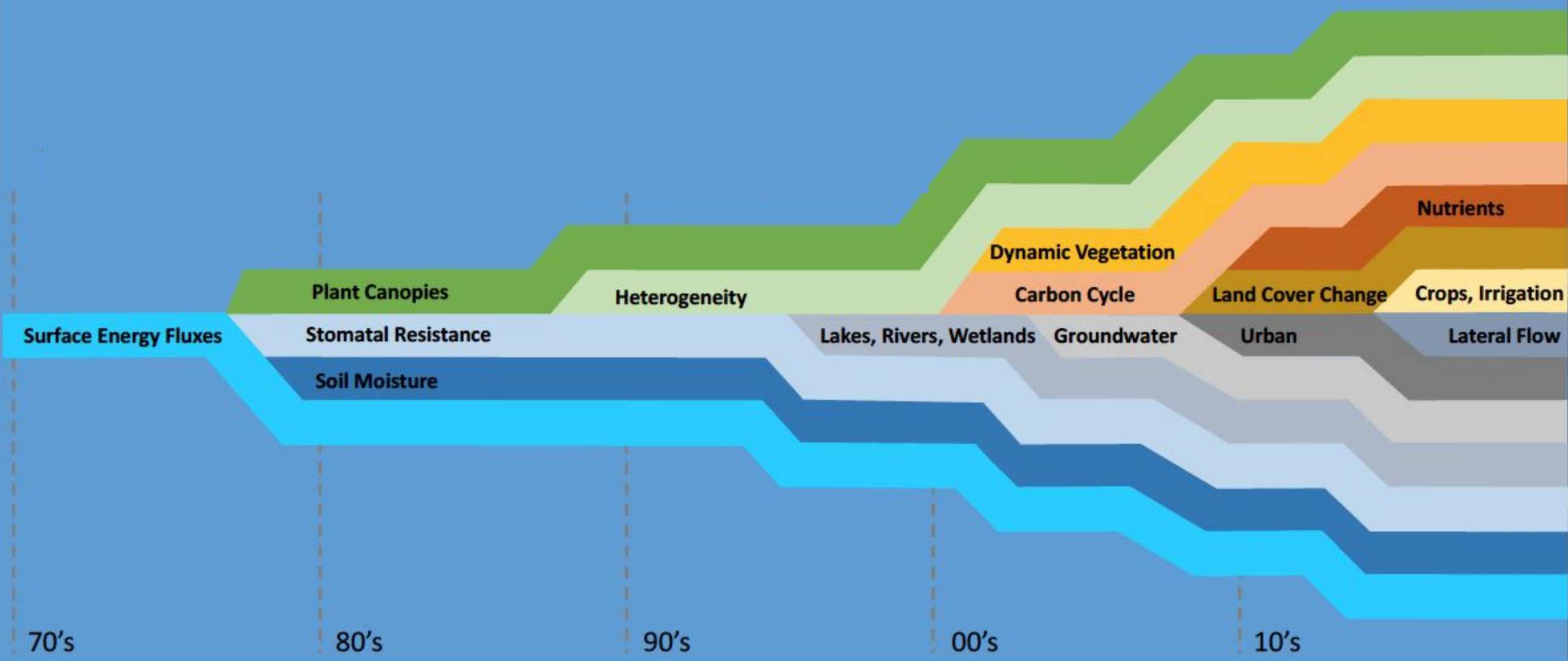
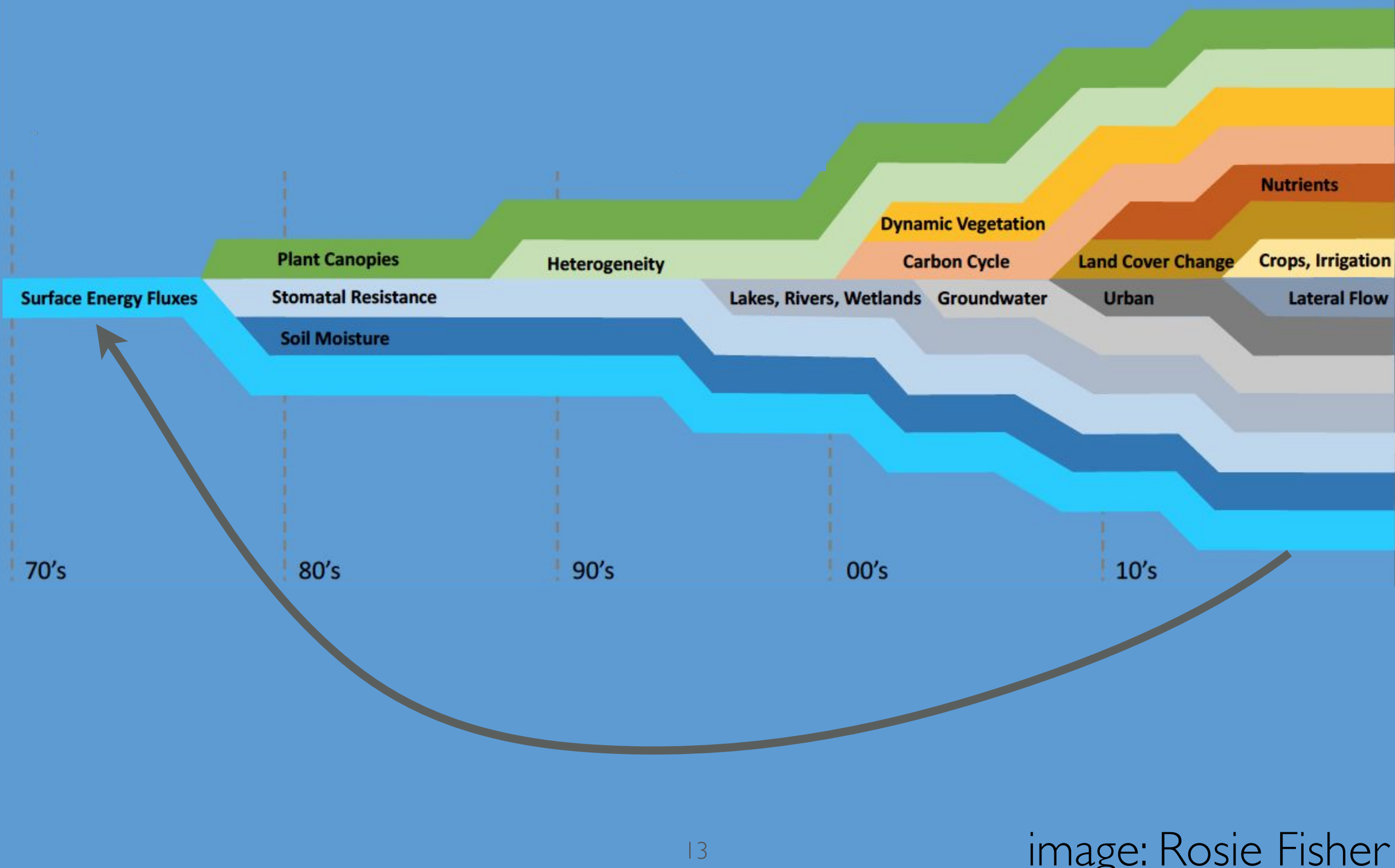


image: Rosie Fisher

How can we test the climate impacts of complexity?



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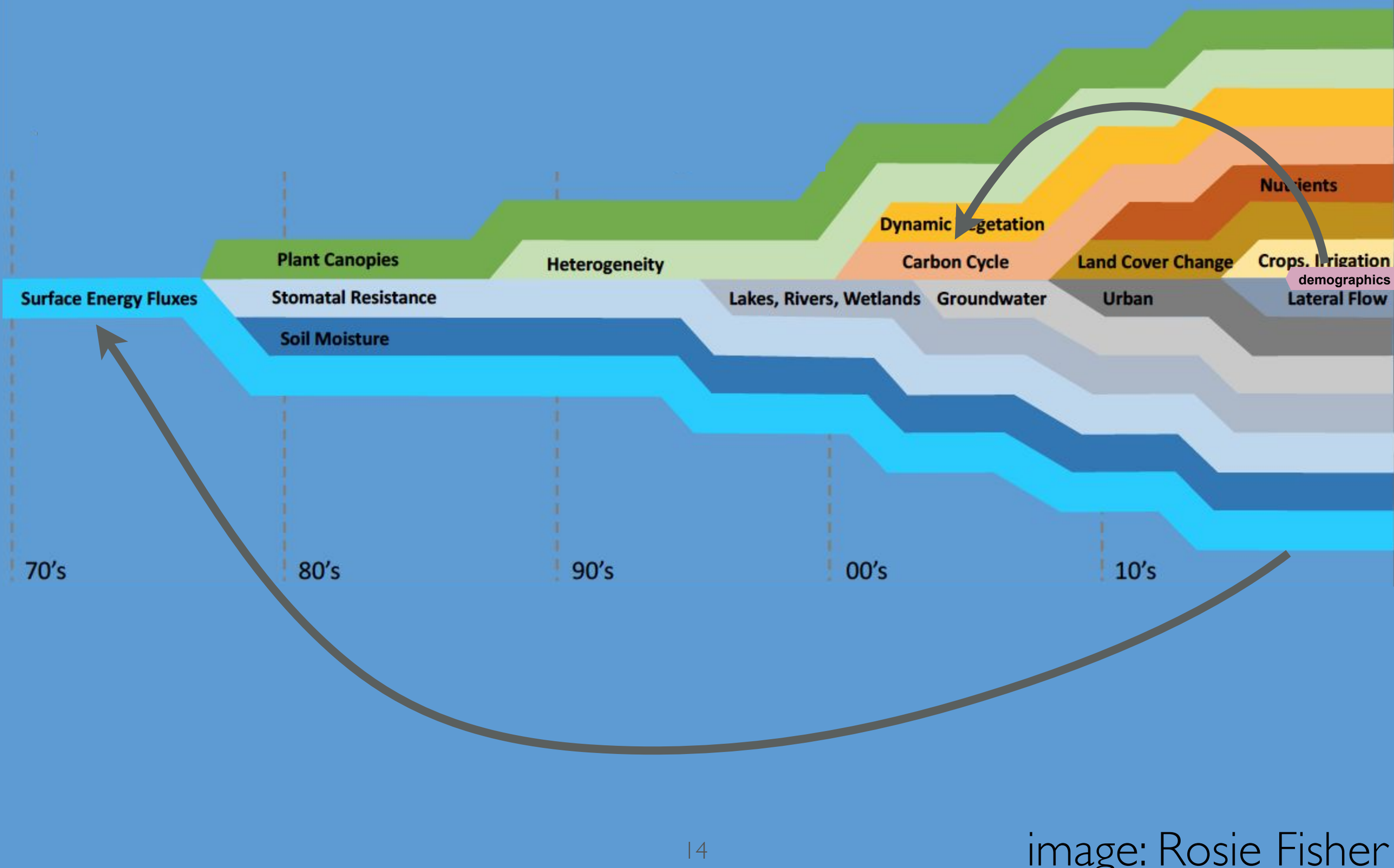
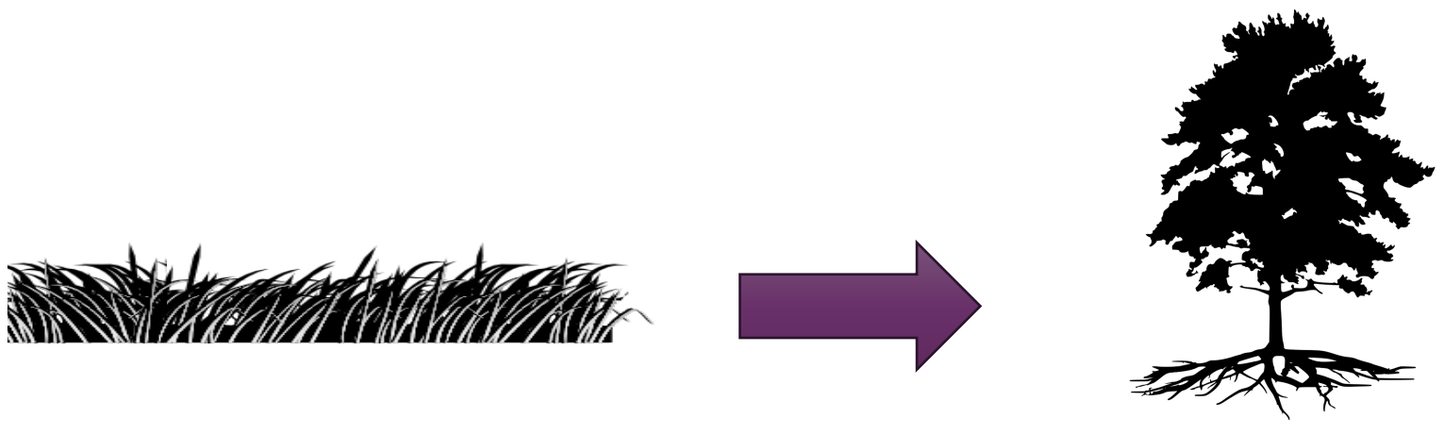


image: Rosie Fisher

Quantifying the climate impacts of changing the land surface

1. In ESMs
2. In ESMs with super simple land
3. A few thoughts on scaling complexity

What is the climate response when grass => trees?



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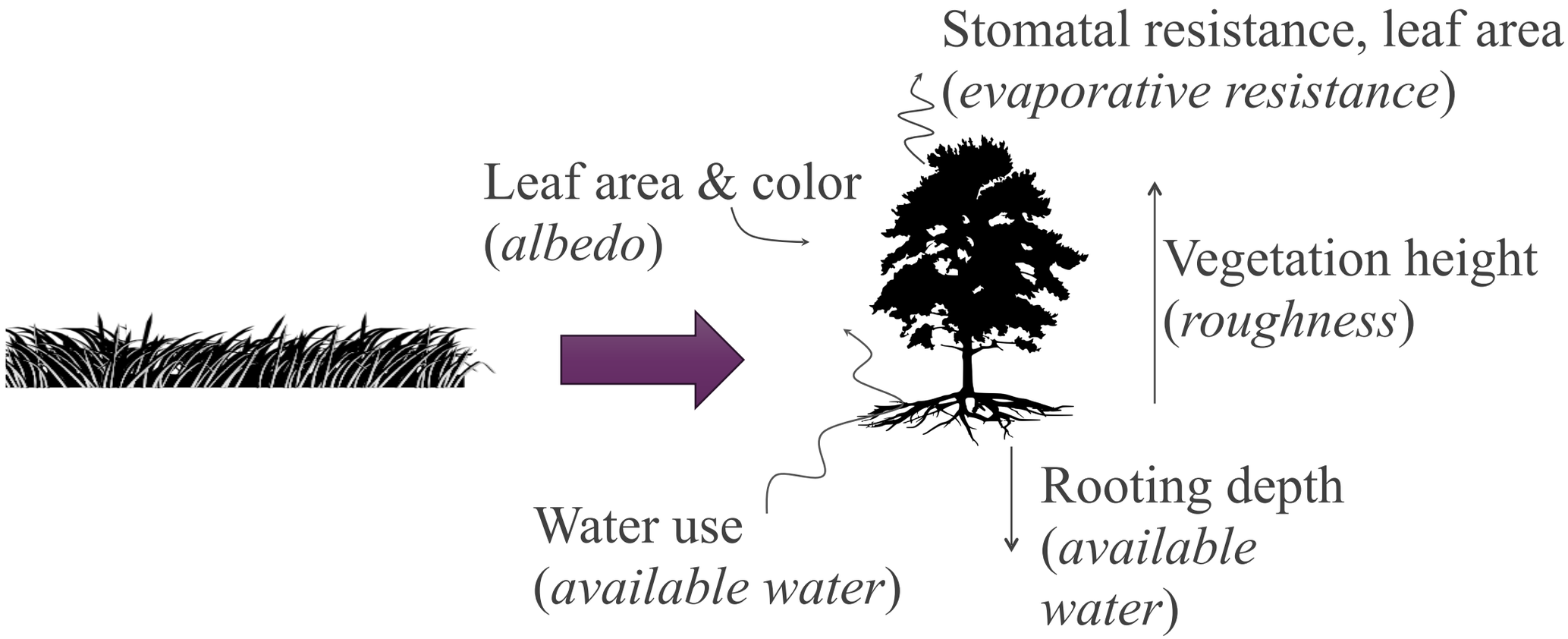
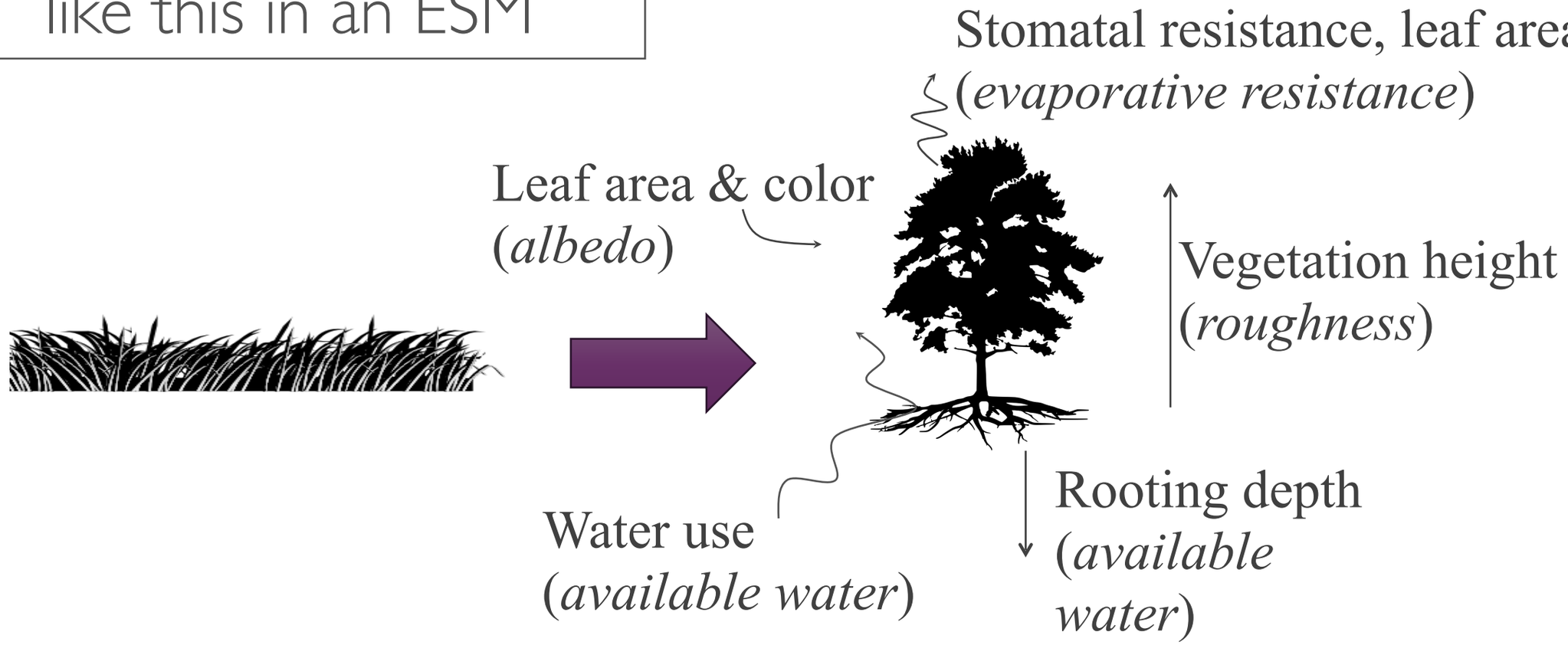
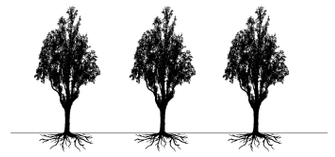


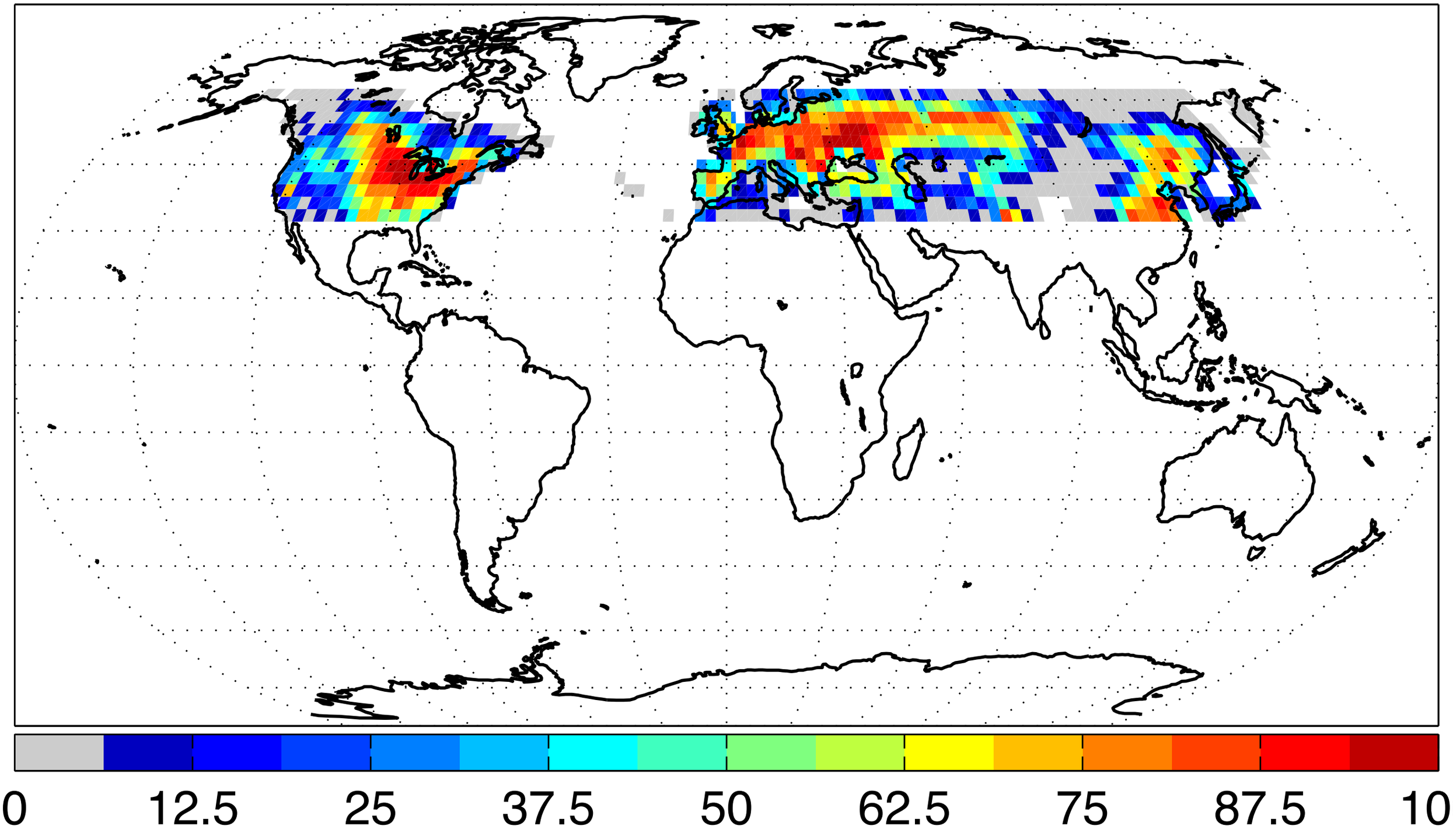
What is the climate response when grass => trees?

We can run experiments like this in an ESM



Crops and C3 grass ⇒ Broadleaf Decid. Trees





Total area converted = 2.1 x 10^7 km^2

Swann et al., 2012 *PNAS*

Surface Temp. Increases with Mid Latitude Trees

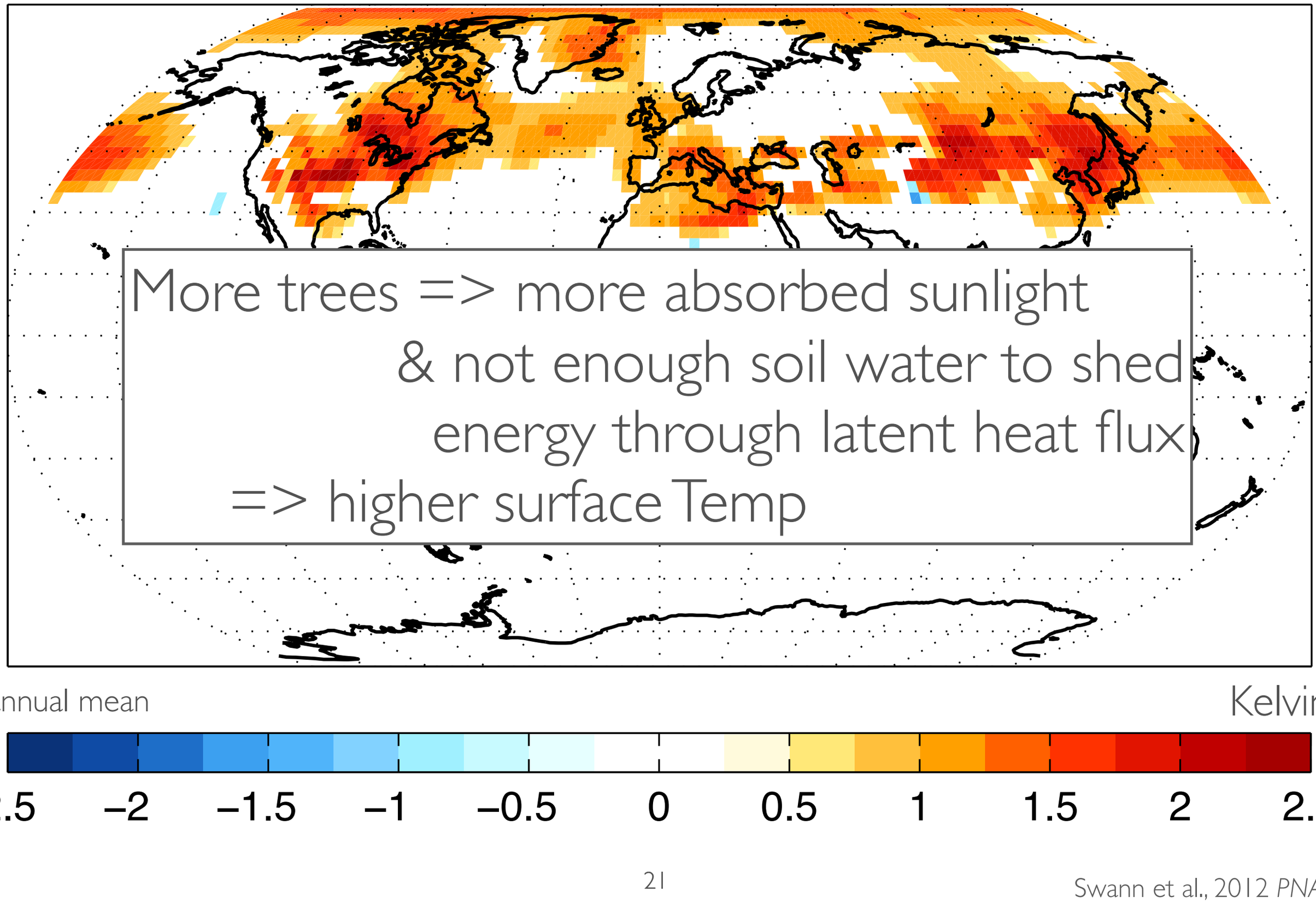
annual mean

Kelvin

−2.5 −2 −1.5 −1 −0.5 0 0.5 1 1.5 2 2.5

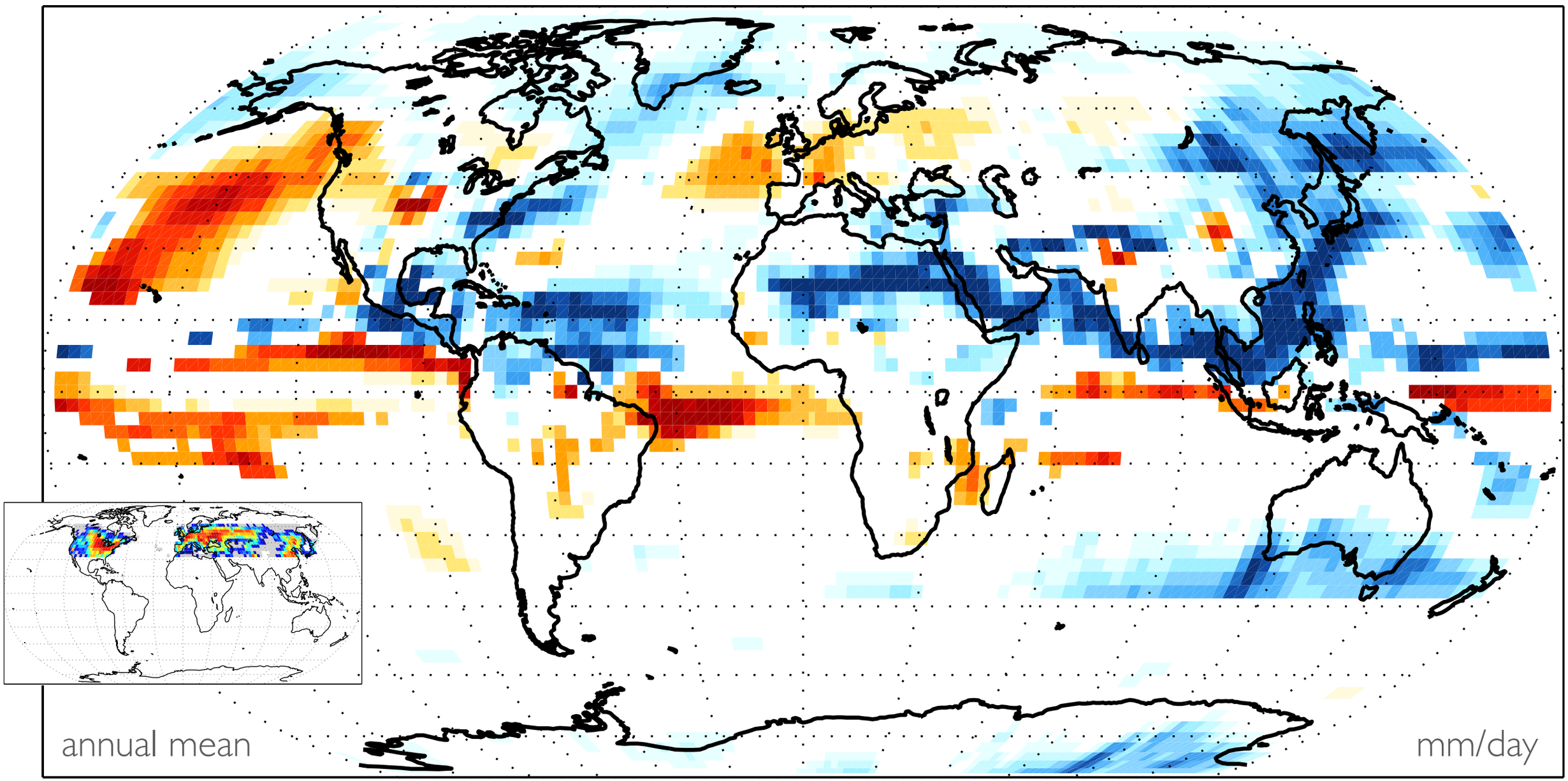
Swann et al., 2012 *PNAS*

Surface Temp. Increases with Mid Latitude Trees



Swann et al., 2012 *PNAS*

Mid Latitude Trees modify *Tropical* Precipitation



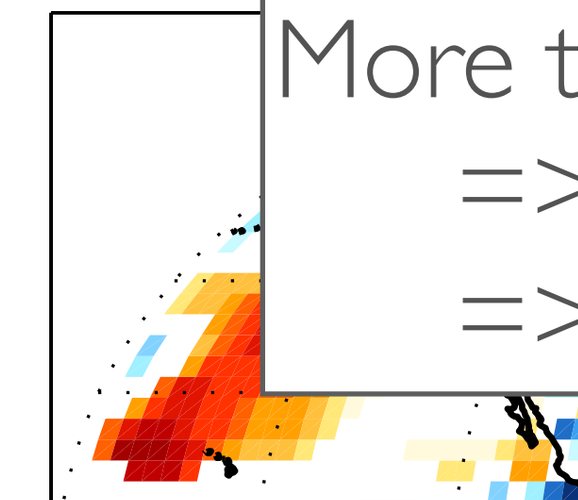
DRY WET

−0.75 −0.6 −0.45 −0.3 −0.15 0 0.15 0.3 0.45 0.6 0.75

Swann et al., 2012 *PNAS*

Mid Latitude Trees modify *Tropical* Precipitation

More trees => more absorbed sunlight
=>bigger N-S energy gradient
=> Hadley Circulation & ITCZ shift



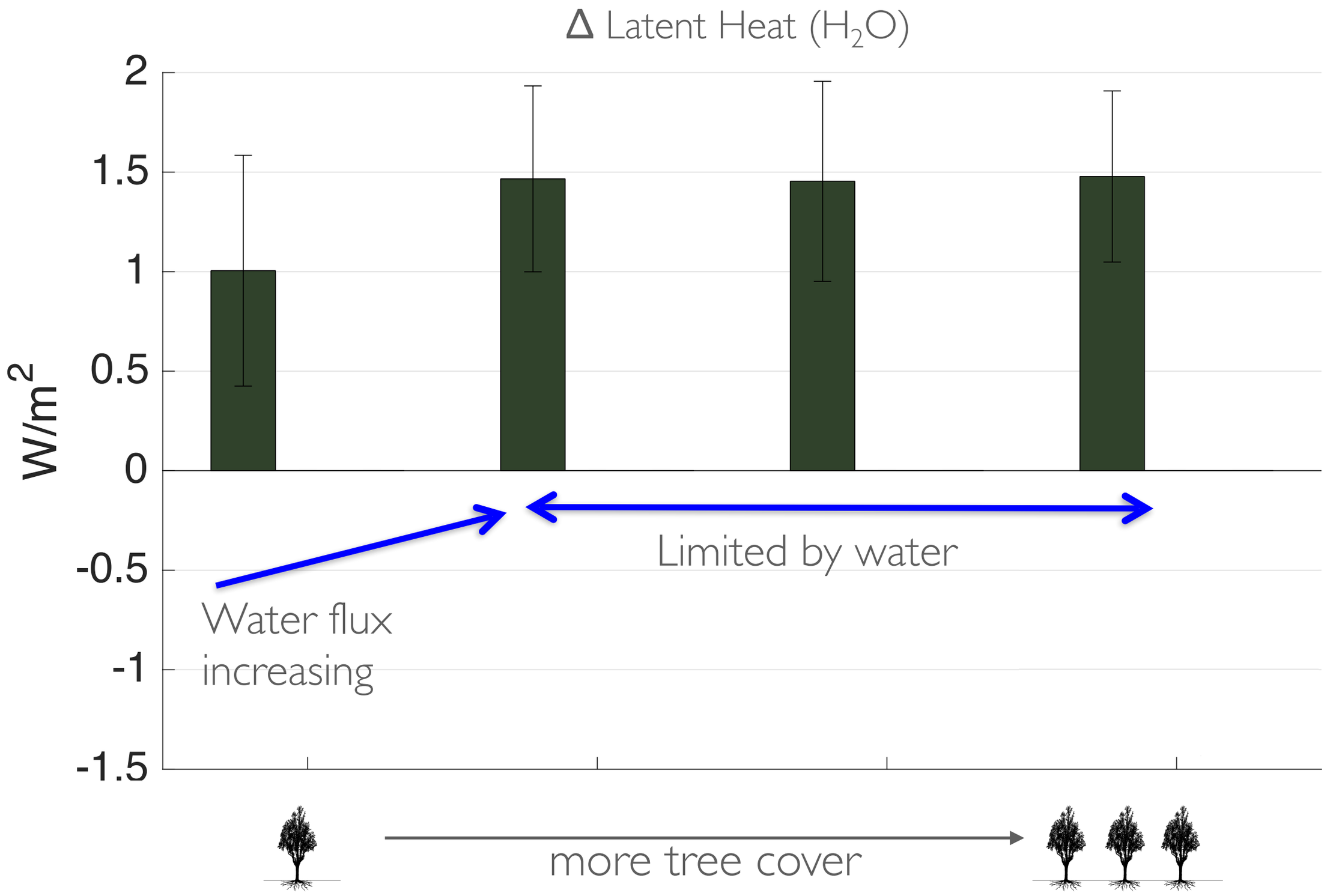
annual mean

DRY WET

−0.75 −0.6 −0.45 −0.3 −0.15 0 0.15 0.3 0.45 0.6 0.75

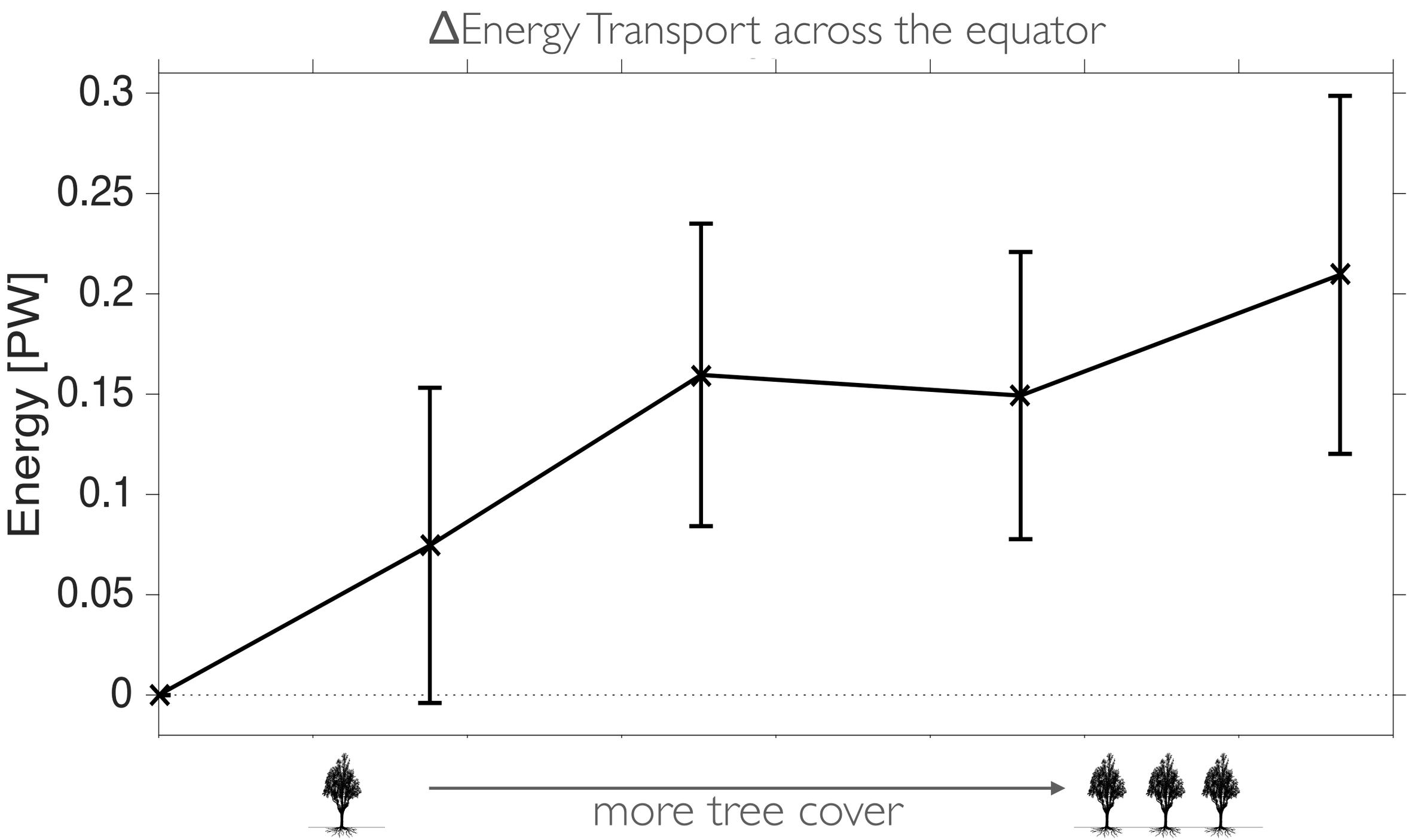
Swann et al., 2012 *PNAS*

Threshold? ΔEvapotranspiration depends on water availability!



Laguë and Swann 2016 *J.Climate*

Circulation responds ~*linearly* to addition of trees



Laguë and Swann 2016 *J.Climate*

Converting more and more grass => trees

Local climate has a ***threshold*** response

Depends on local water balance

Controlled by latent vs. sensible heat

Global climate has a ***linear*** response

Depends on large scale energy gradients

Controlled by surface albedo

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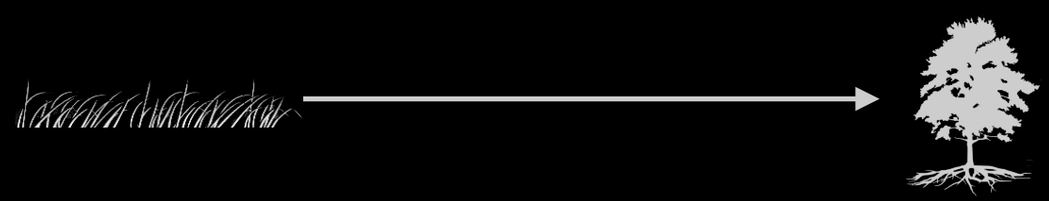
Take Home Point #1



Local and *Global* climate responses are sensitive to different land surface properties

What is the climate response to changing trees, and ***why***?

How do different surface properties impact climate?

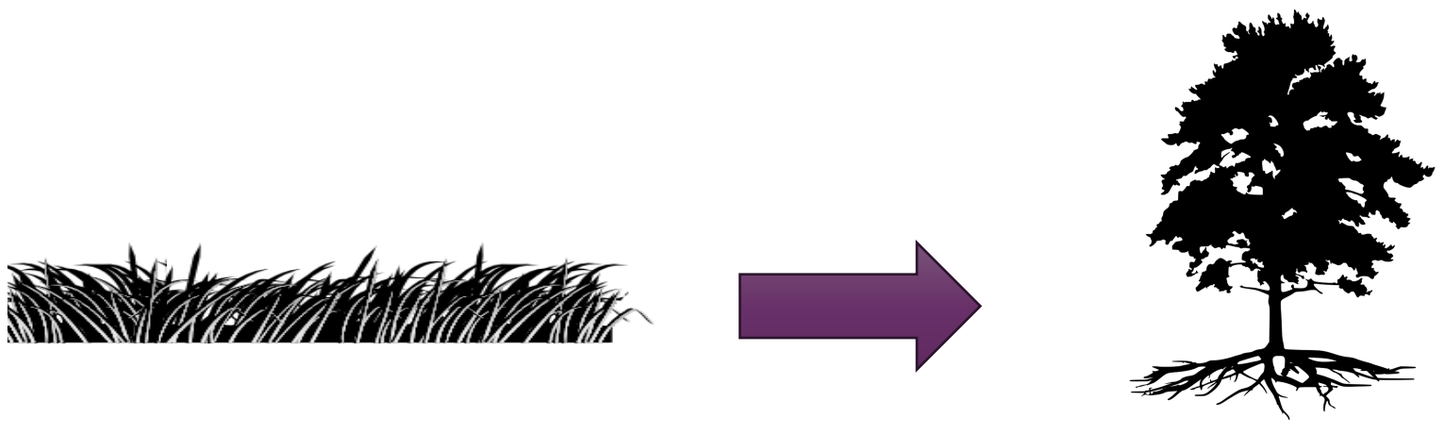
i.e. *albedo* vs. *evaporative resistance*

What role does the *atmosphere* play relative to the *land*?

Local vs. *remote* atmospheric feedbacks

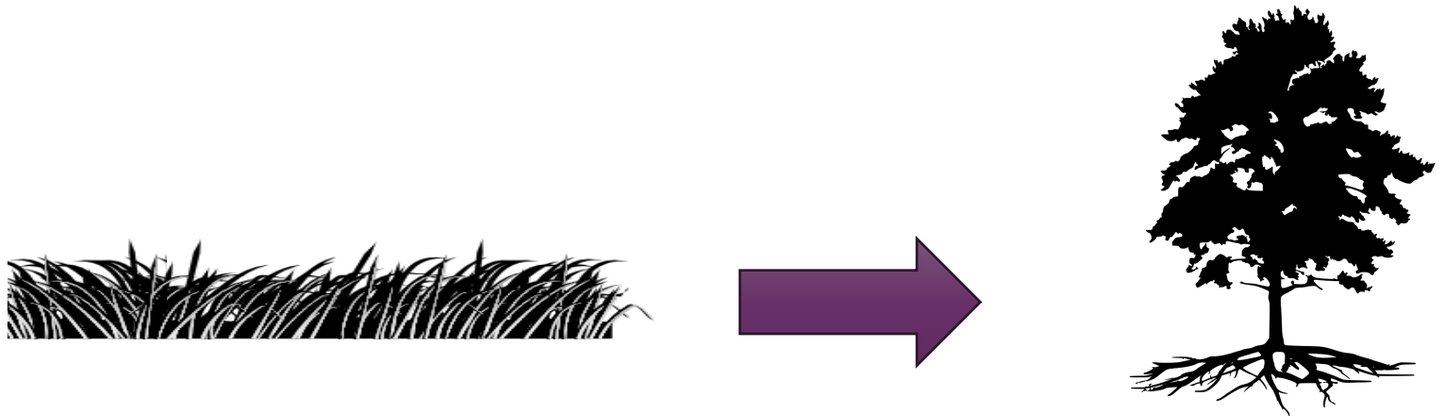
What really is the climate response to changing trees?

(And ***why?***)



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

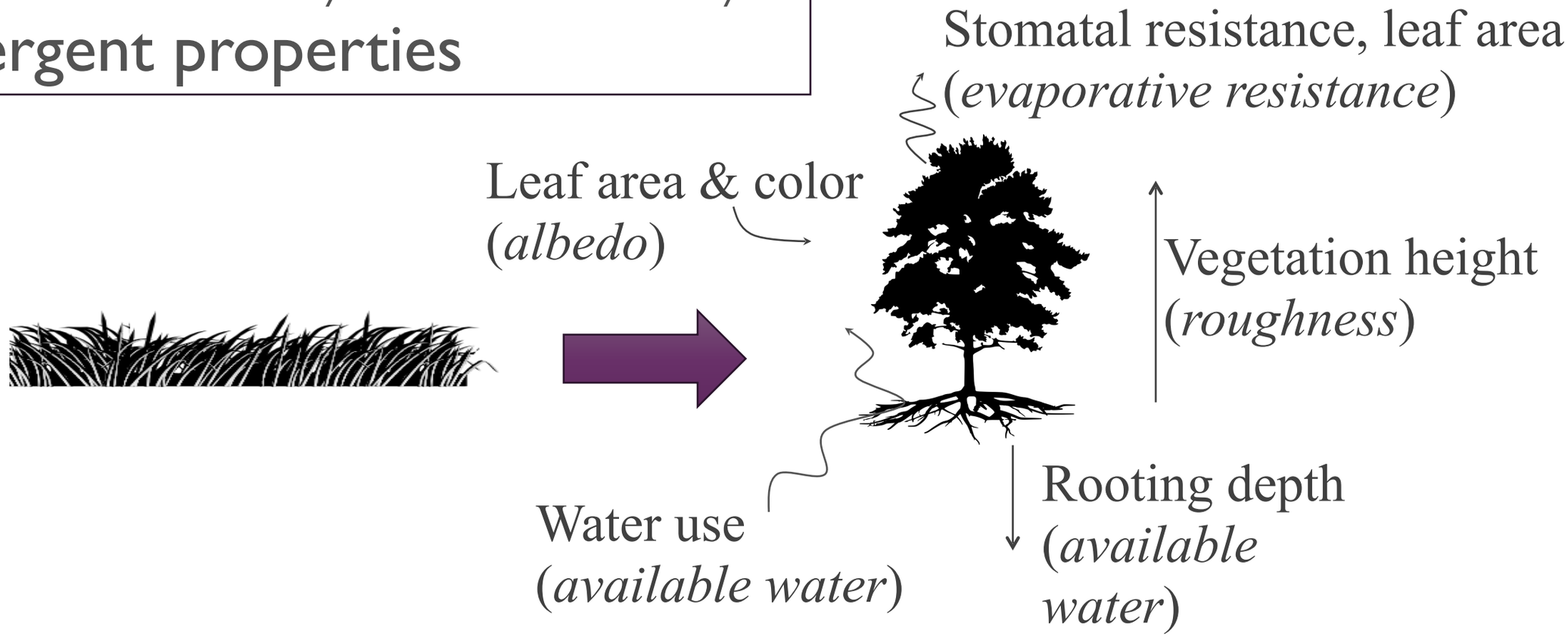
Ideally we could change ***one*** aspect at a time to isolate the effect



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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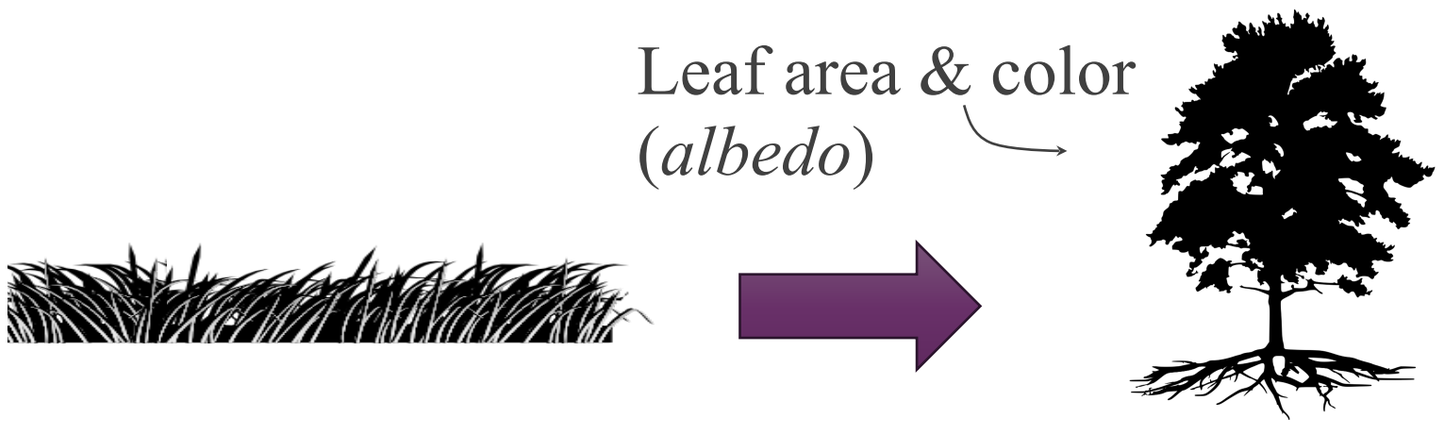


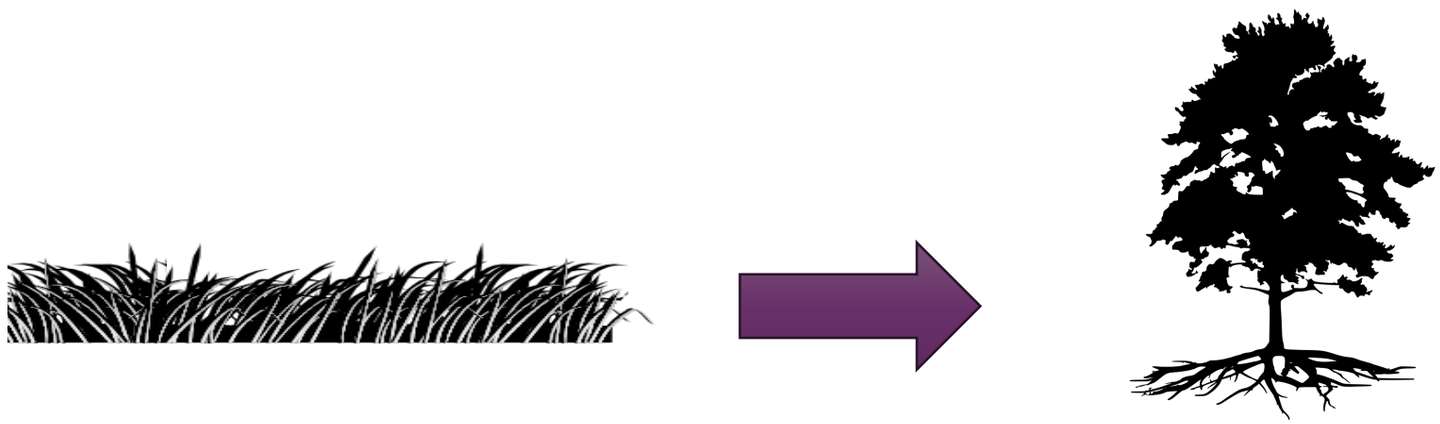
e.g. albedo is not set in most climate models.
It is **calculated**.

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!

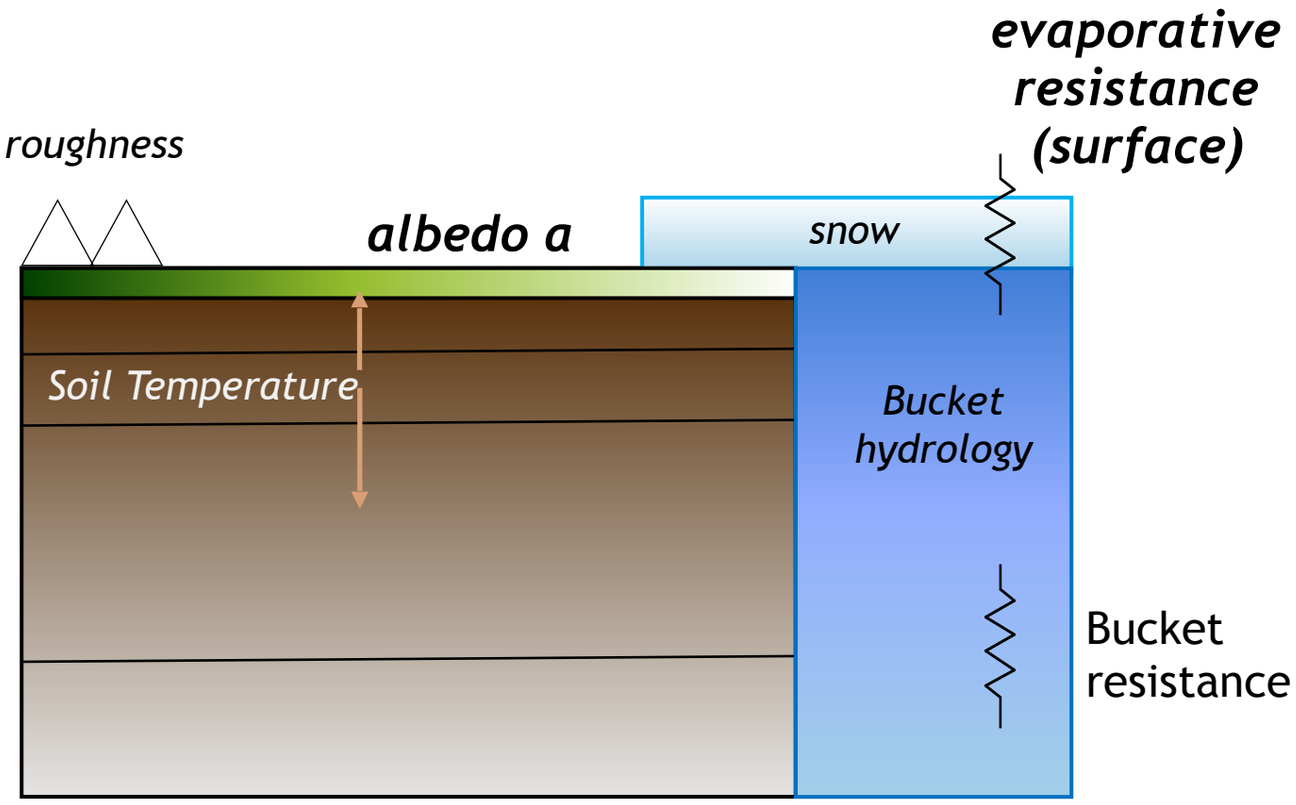


What really is the climate response to changing trees? And ***why***?

=> 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

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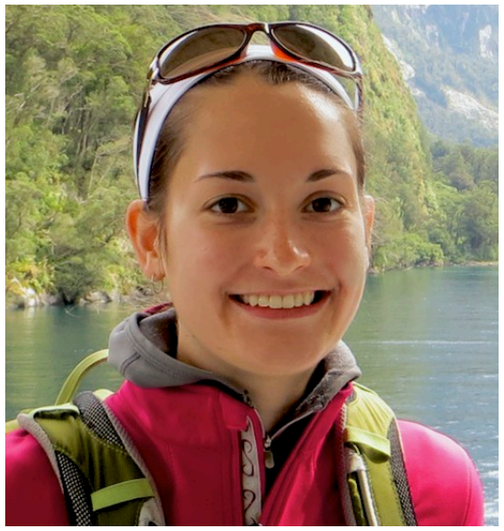

Marysa Laguë

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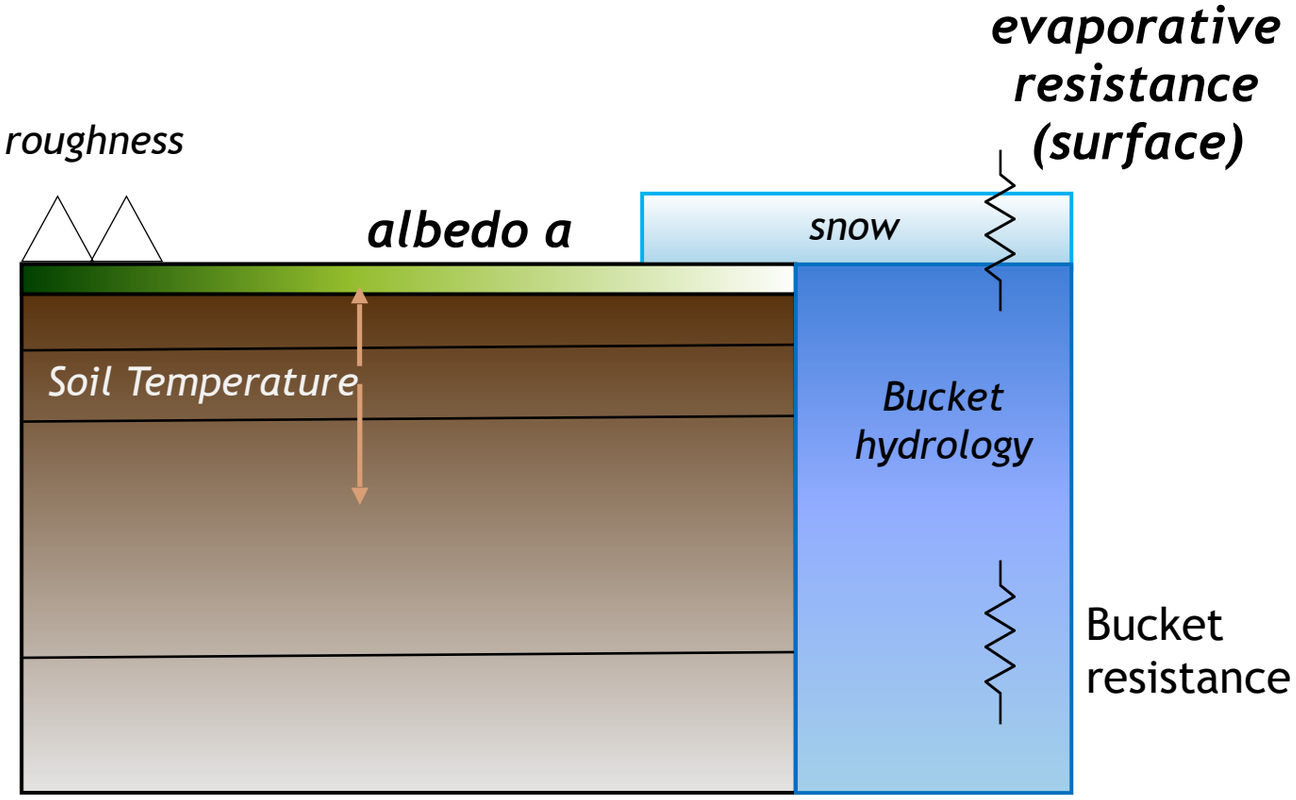

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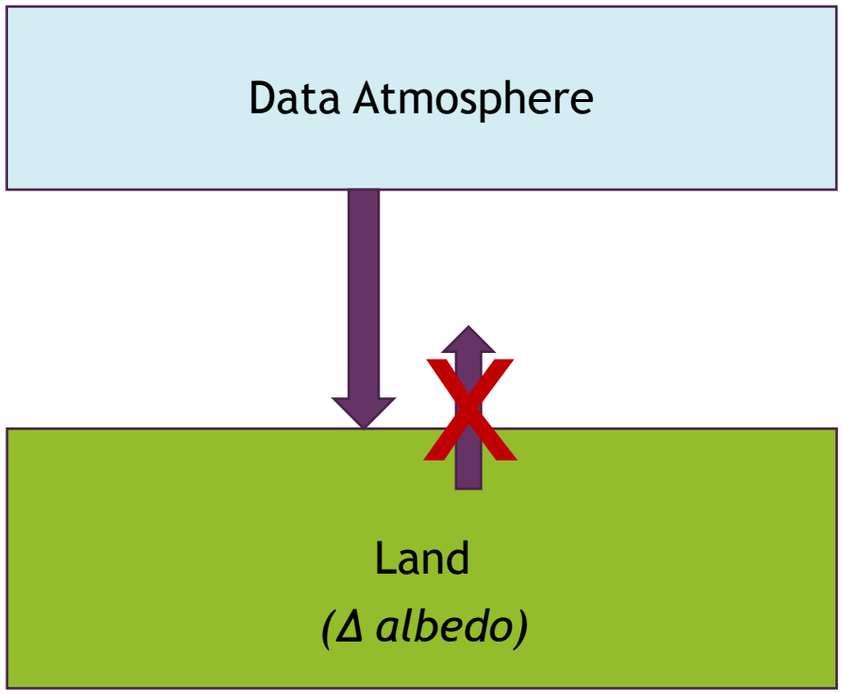
Work with Marysa Laguë & Gordon Bonan

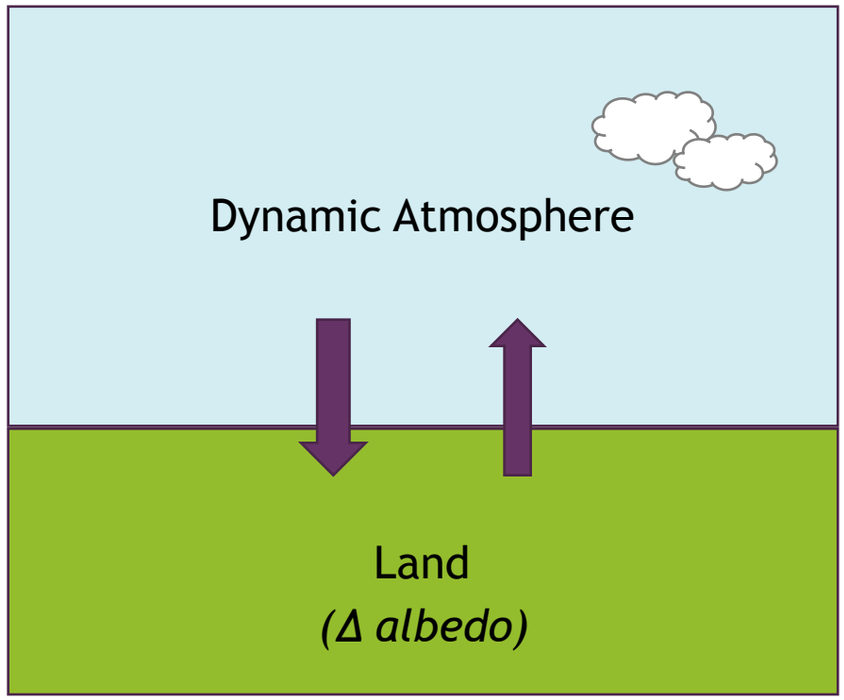
Two parts of the total climate response to a surface property change:

Land-only (**forced** response)



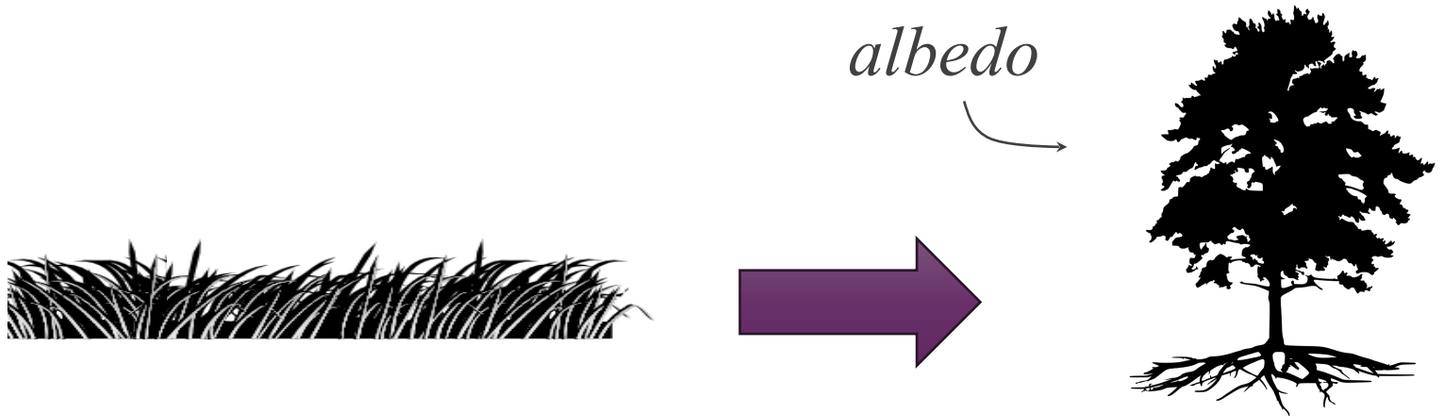
Changes in the surface energy budget uncoupled from the atmosphere

Coupled
(Forcing + **Feedbacks**)



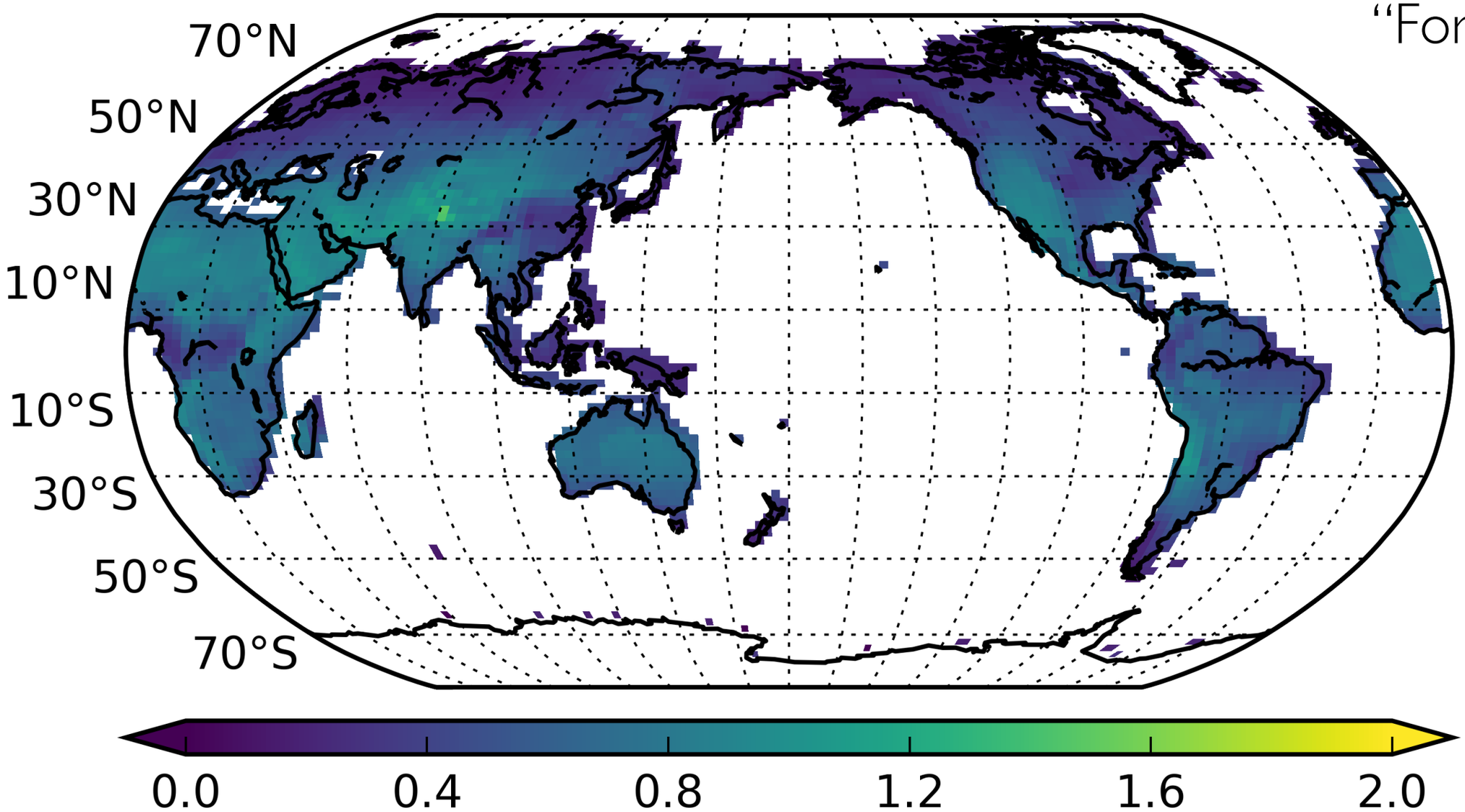
Changes in the surface energy budget that include feedbacks from the atmosphere

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

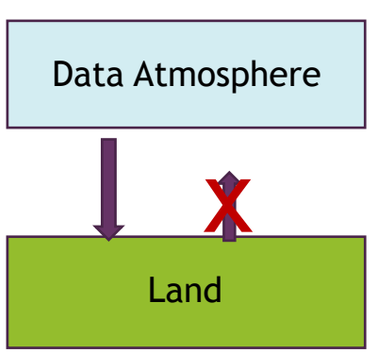


Temperature response to a change in surface albedo of 0.1

Land only
"Forcing"



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

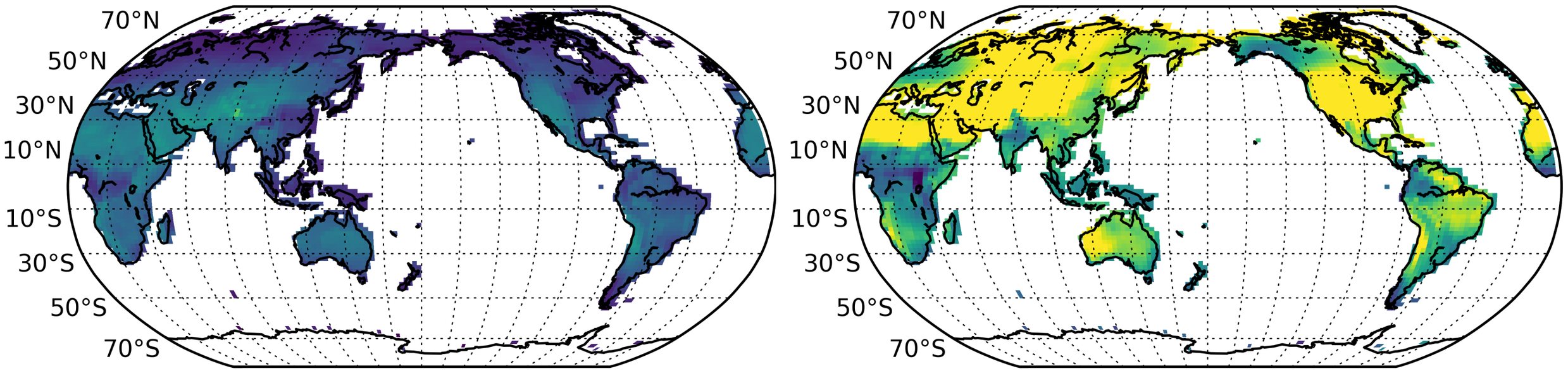


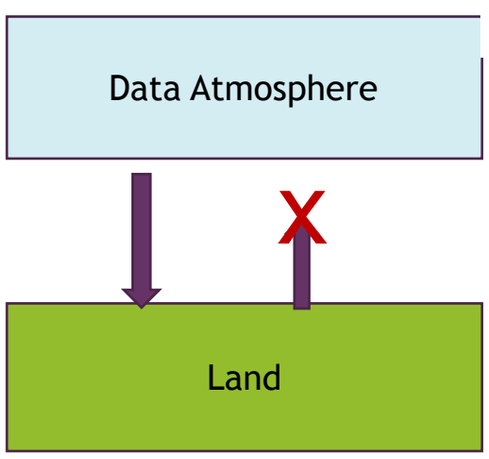
Work with Marysa Laguë & Gordon Bonan

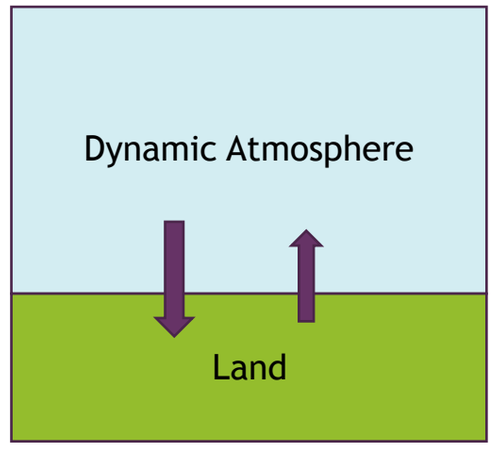
Feedback from the atmosphere is large!

Land only
"Forcing"

Land + Atmosphere
"Forcing + Feedback"







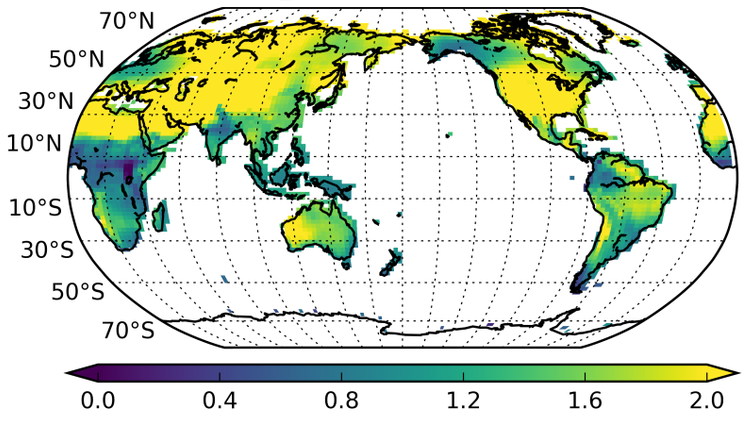
Work with Marysa Laguë & Gordon Bonan

We can quantify the feedback from the atmosphere

Feedback
(Warming due to atmosphere)

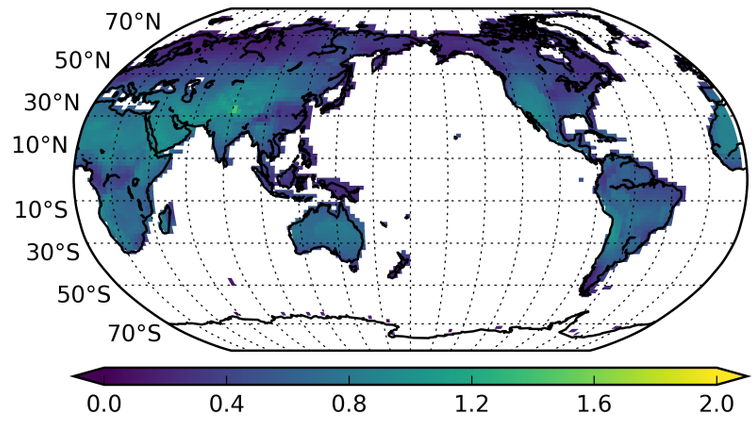
=

Land + Atmosphere
"Forcing + Feedback"



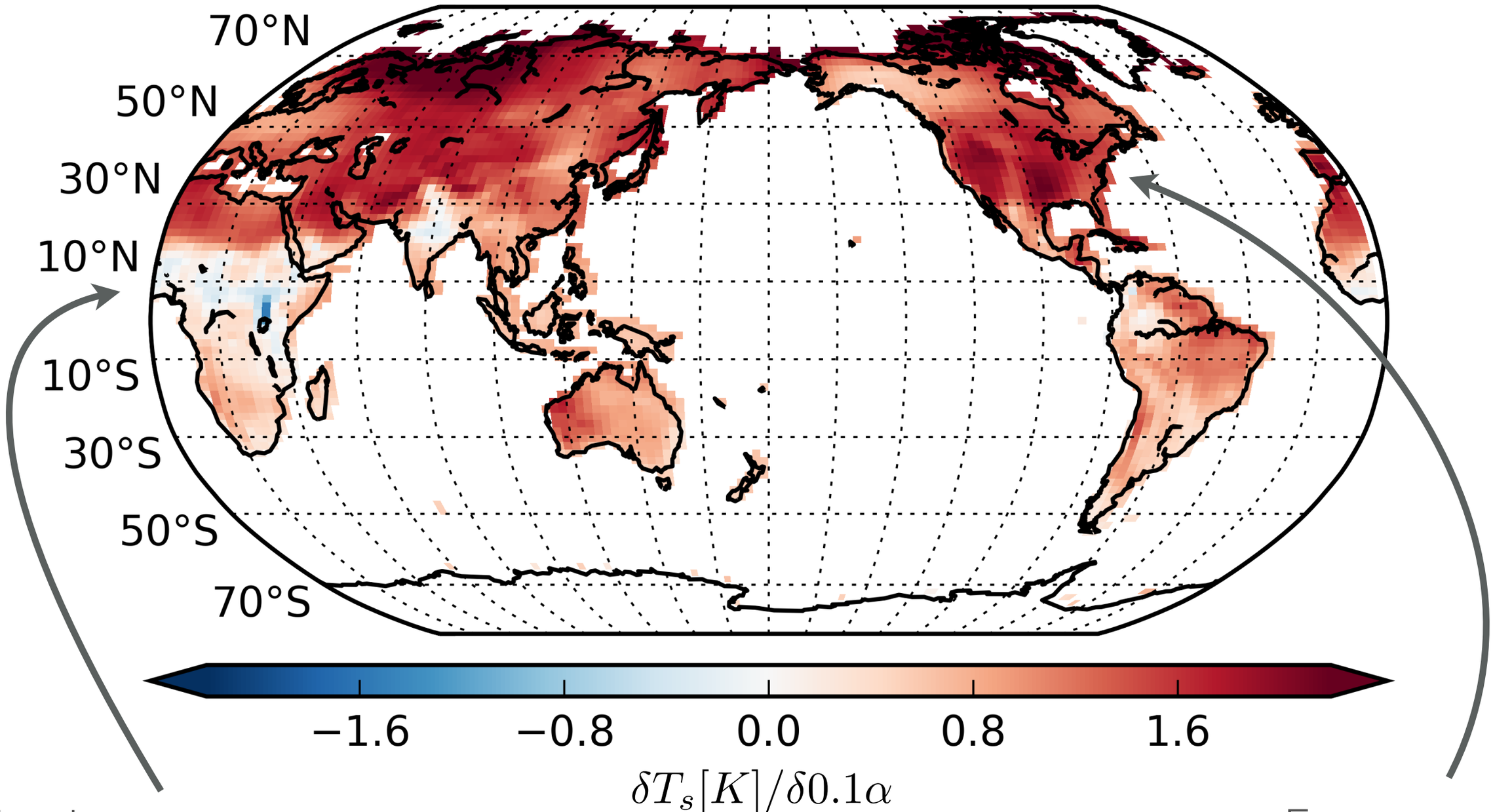
-

Land only
"Forcing"



Work with Marysa Laguë & Gordon Bonan

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

Work with Marysa Laguë & Gordon Bonan

What is the climate response to changing trees, and ***why***?

What role does the *atmosphere* play relative to the *land*?

Local vs. *remote* atmospheric feedbacks

What is the climate response to changing trees, and ***why***?

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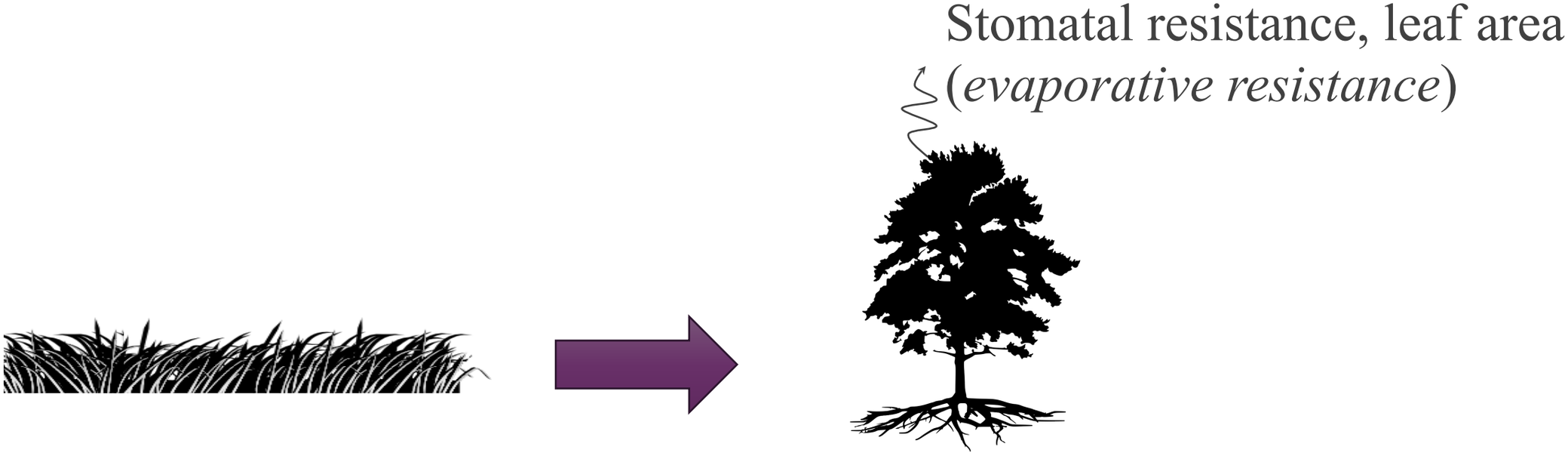
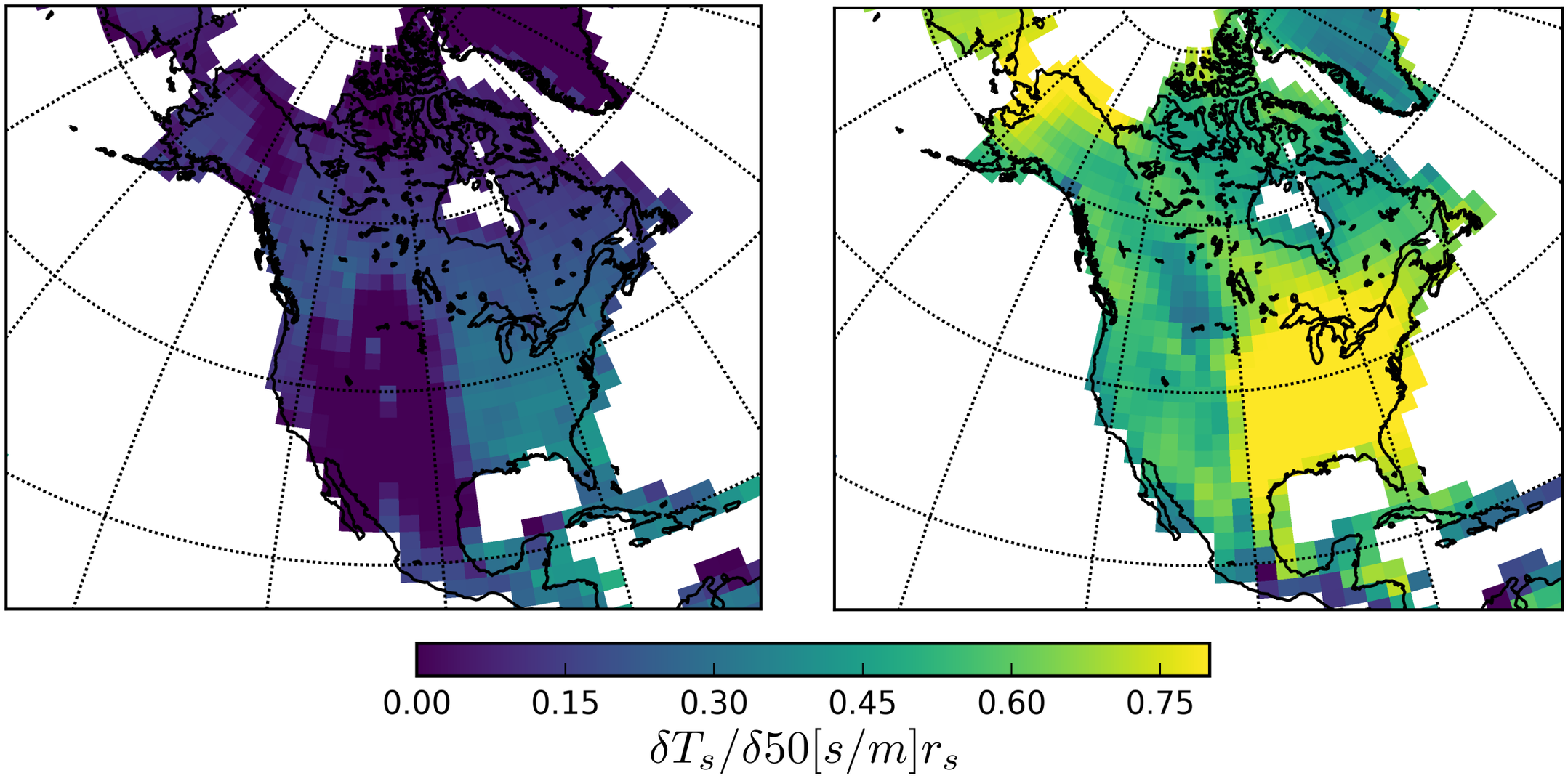
Local vs. *remote* atmospheric feedbacks



Surface temperature response mostly coming from atmospheric feedbacks

Land only
"Forcing"

Land + Atmosphere
"Forcing + Feedback"



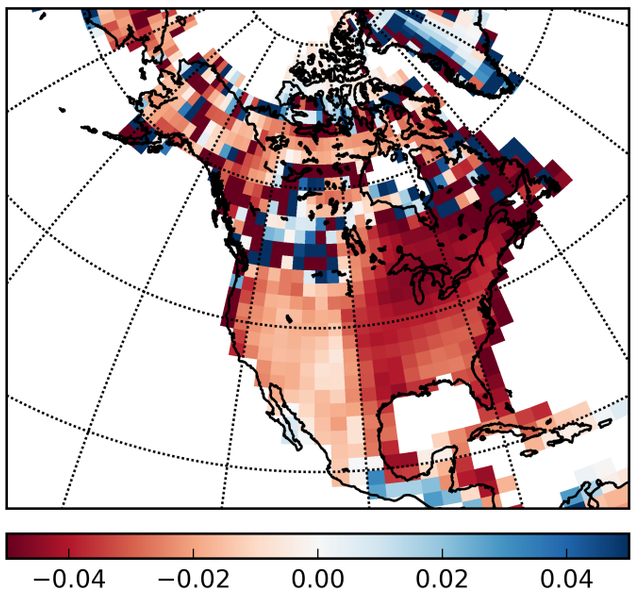
Temperature response to a change in evap resistance of 50s/m

Evaporative Resistance alters Evaporative Fraction

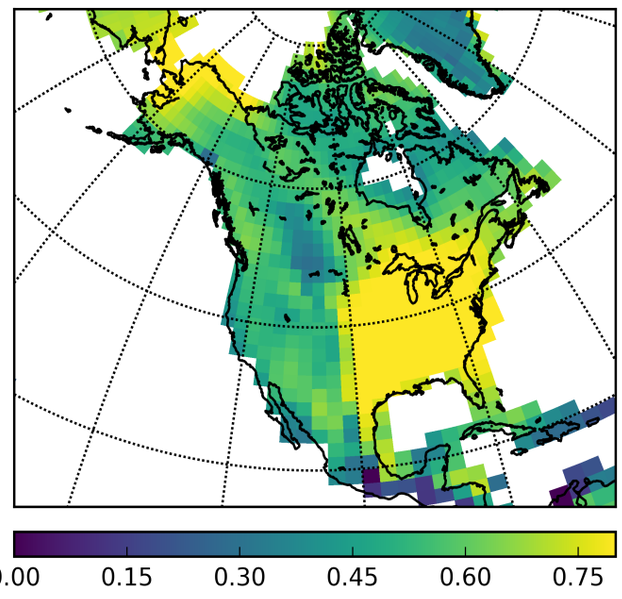
↑ resistance

=

↓ evaporative fraction



Evaporative Fraction

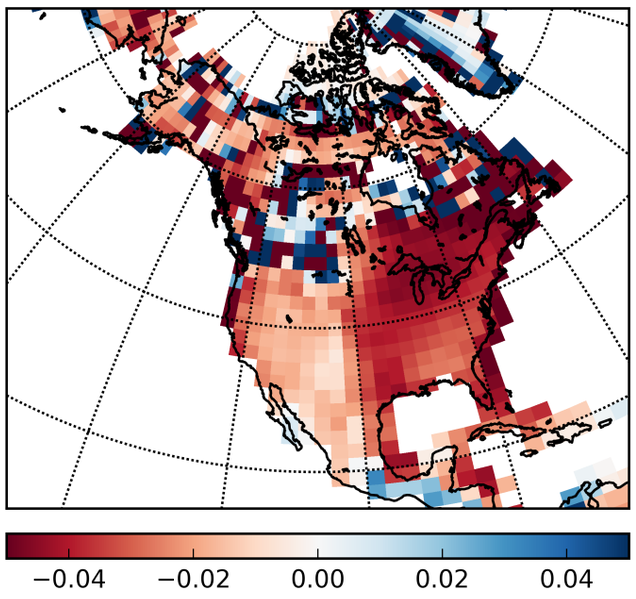


Surface Temperature

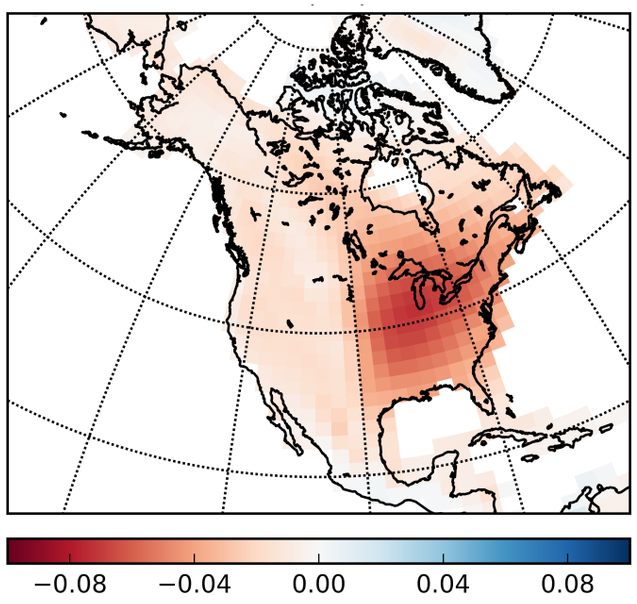
Evaporative Fraction alters Low Clouds

↑ resistance
=
↓ evaporative fraction

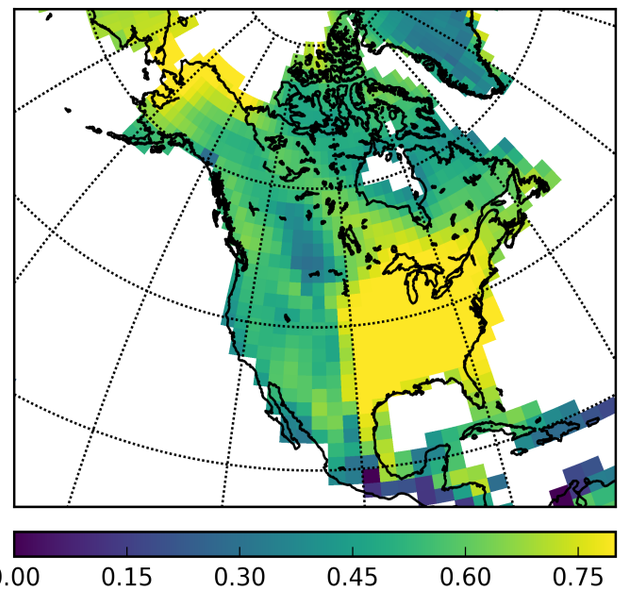
↓ evaporative fraction
=
↓ low clouds



Evaporative Fraction



Low Clouds



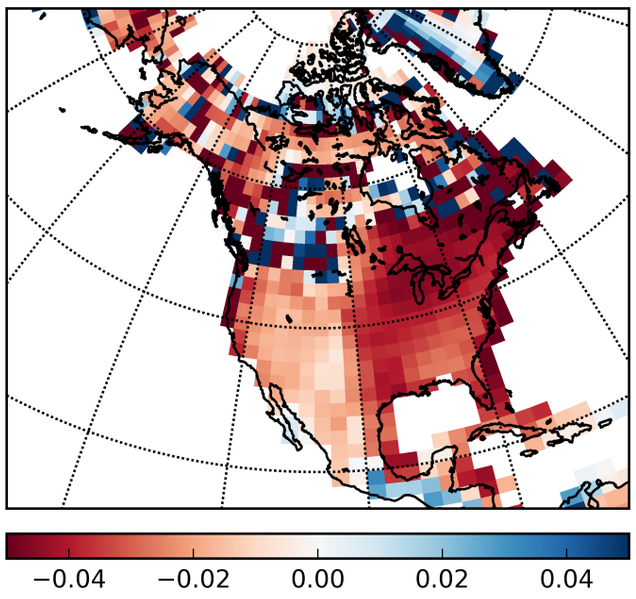
Surface Temperature

Low Clouds allow more Solar Rad to reach the surface

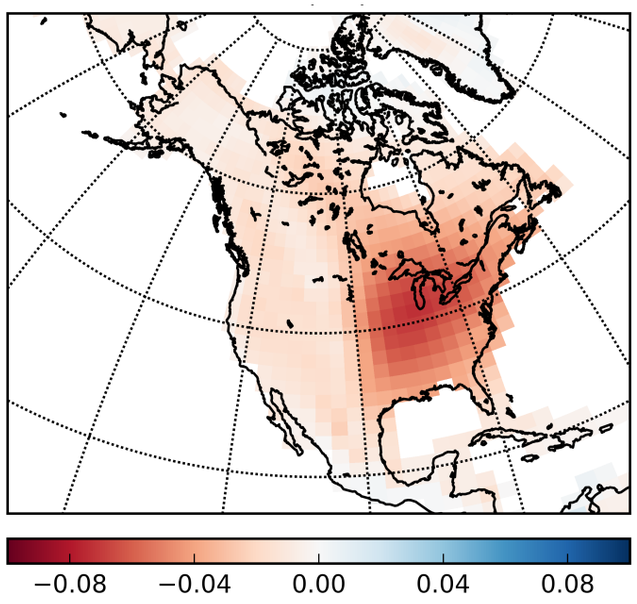
↑ resistance
=
↓ evaporative fraction

↓ evaporative fraction
=
↓ low clouds

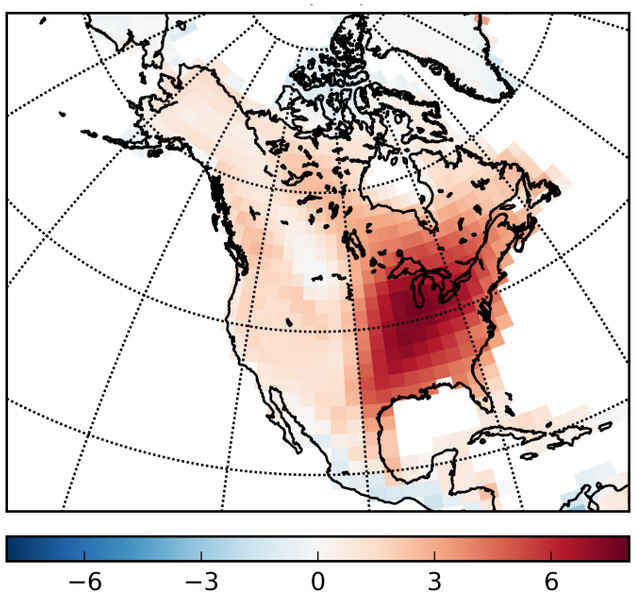
↓ low clouds
=
↑ sun reaching ground



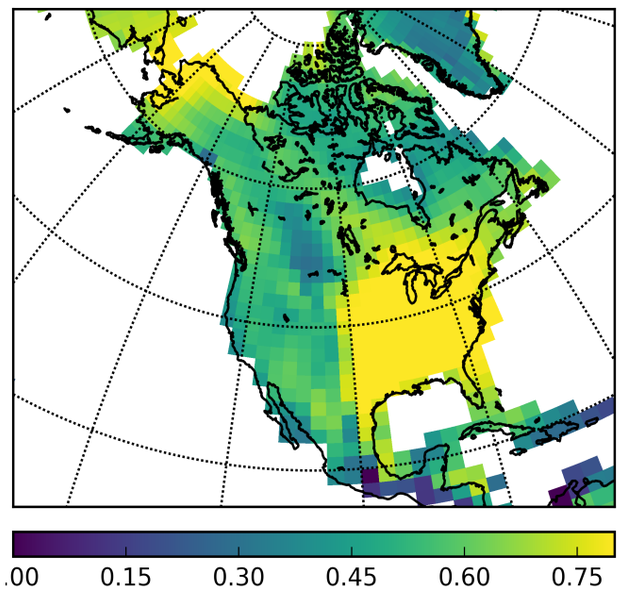
Evaporative Fraction



Low Clouds



Downwelling Solar



Surface Temperature

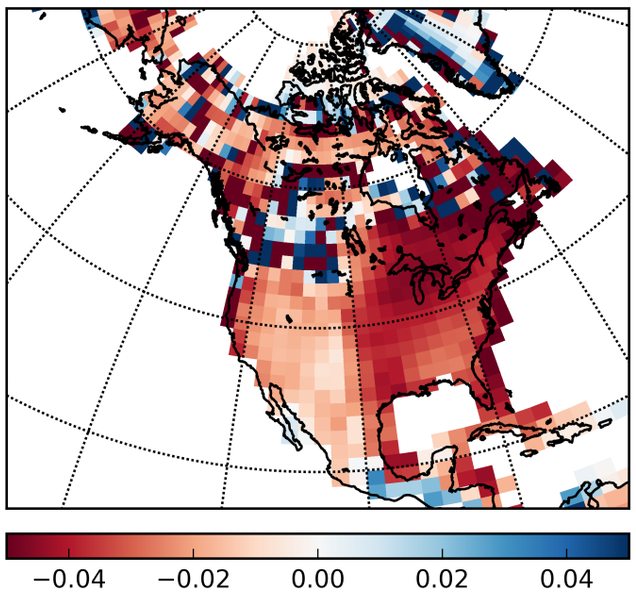
More incoming solar increases temperature

↑ resistance
=
↓ evaporative fraction

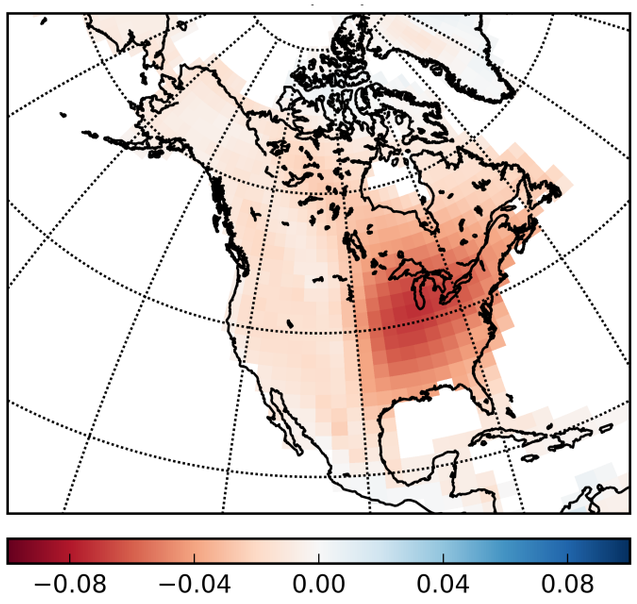
↓ evaporative fraction
=
↓ low clouds

↓ low clouds
=
↑ sun reaching ground

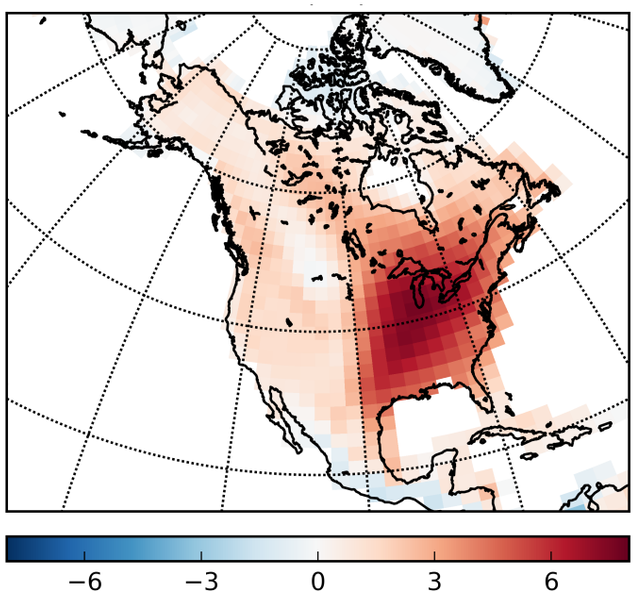
↑ sun reaching ground
=
↑ surface T



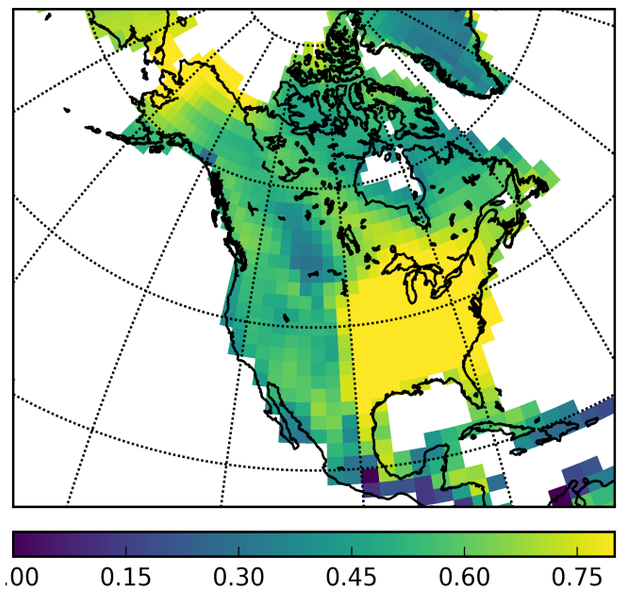
Evaporative Fraction



Low Clouds



Downwelling Solar



Surface Temperature

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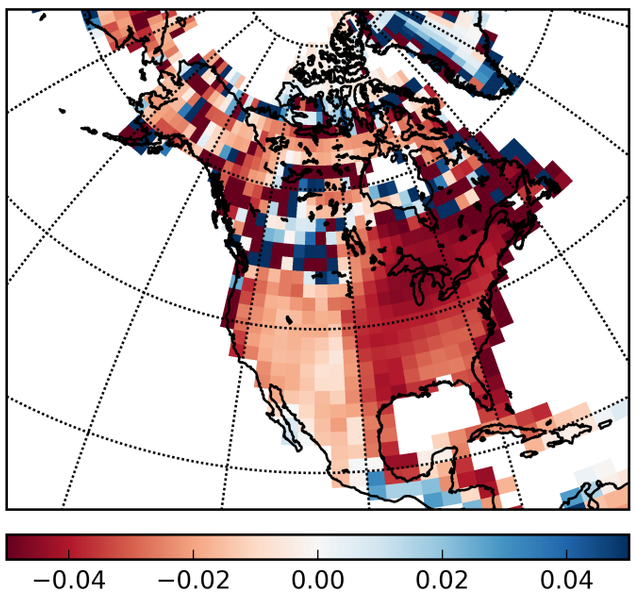
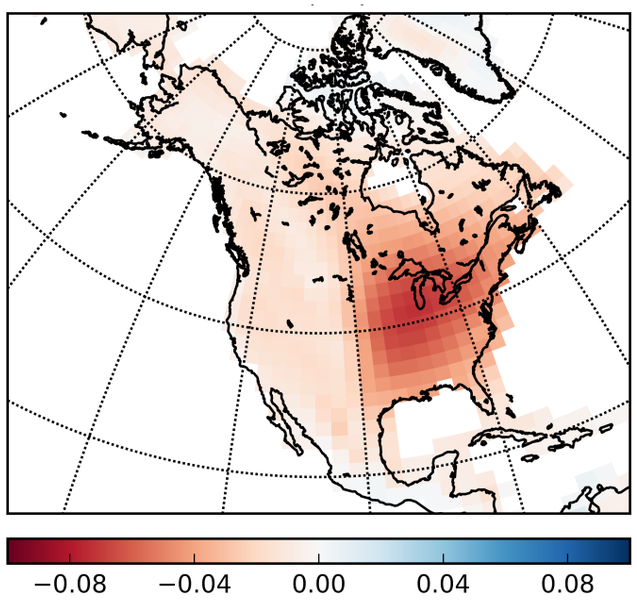
↓ low clouds
=
↑ sun reaching ground

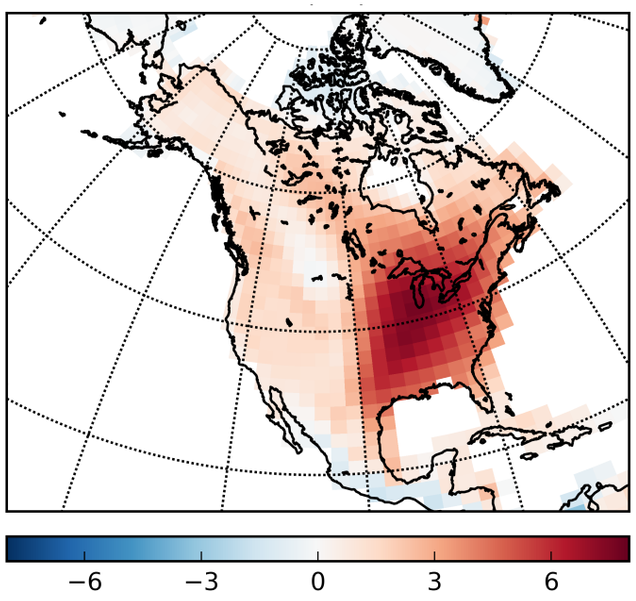
↑ sun reaching ground
=
↑ surface T



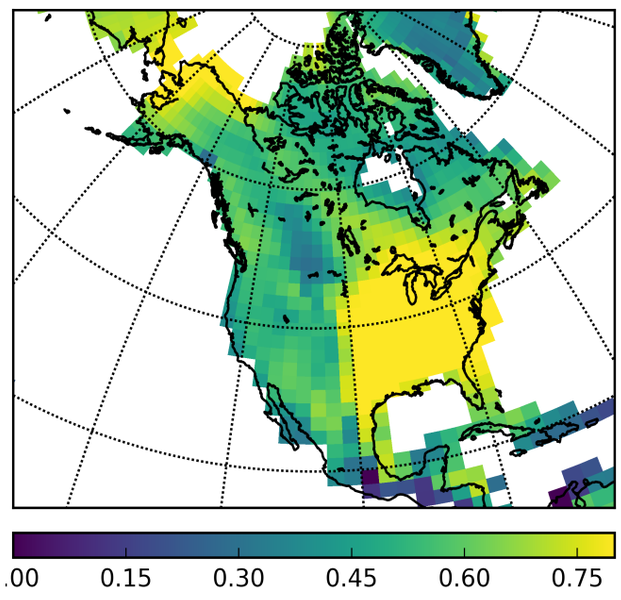
Evaporative Fraction



Low Clouds



Downwelling Solar

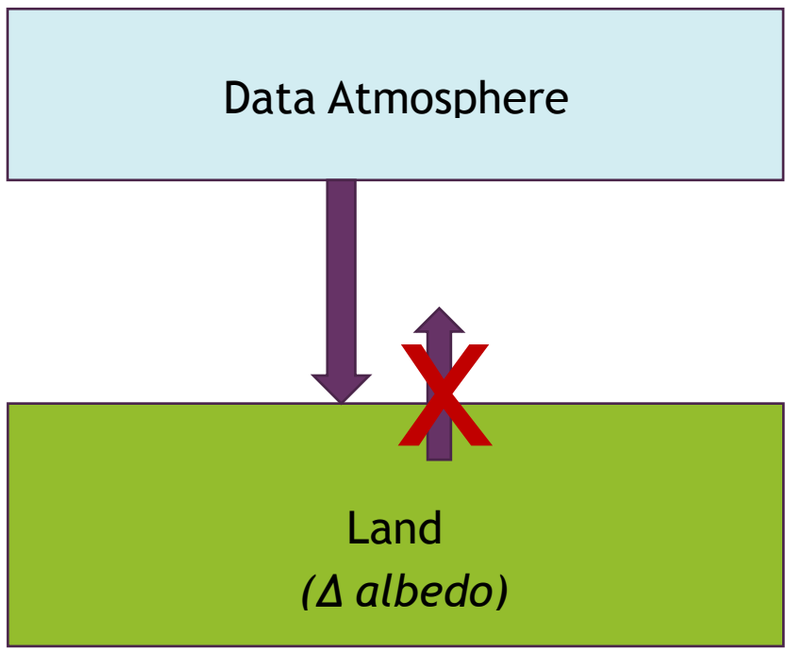


Surface Temperature

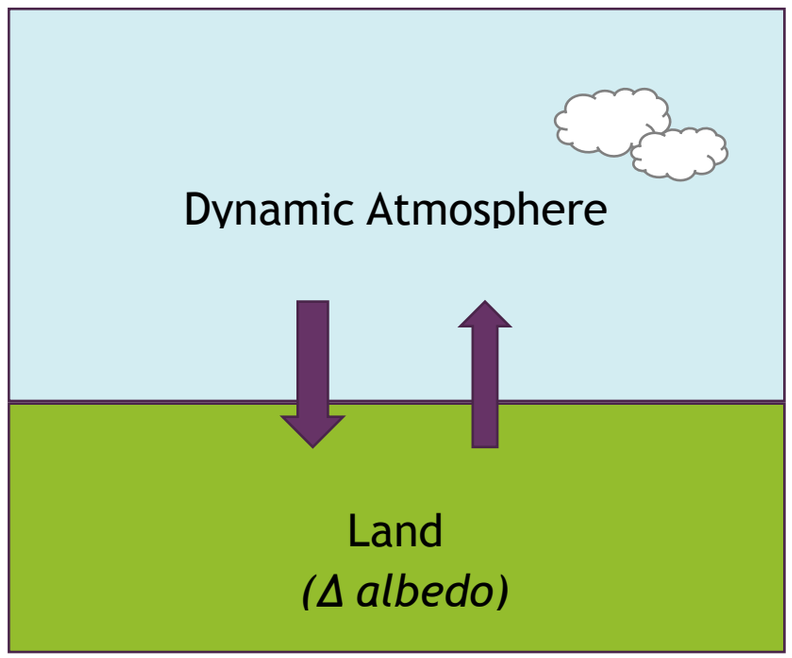
This is a mostly *local* atmospheric feedback

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

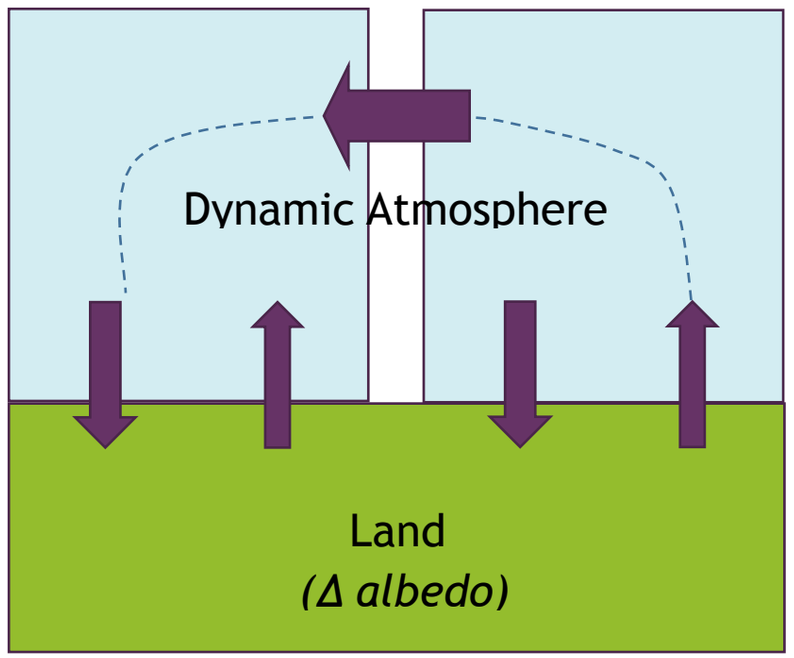
Land-only (**forced** response)



Local Atmospheric **Feedback**



Remote Atmospheric **Feedback**

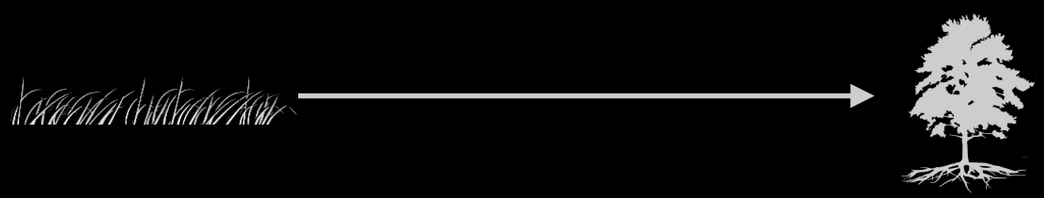


Take Home point #2

Atmospheric ***feedbacks*** are large!

We can't quantify the climate impact of the land surface without the atmosphere

Take Home point #3



Simple versions of land models help us to figure out where the atmosphere is sensitive to the land surface and ***why***

How can we test the climate impacts of complexity?

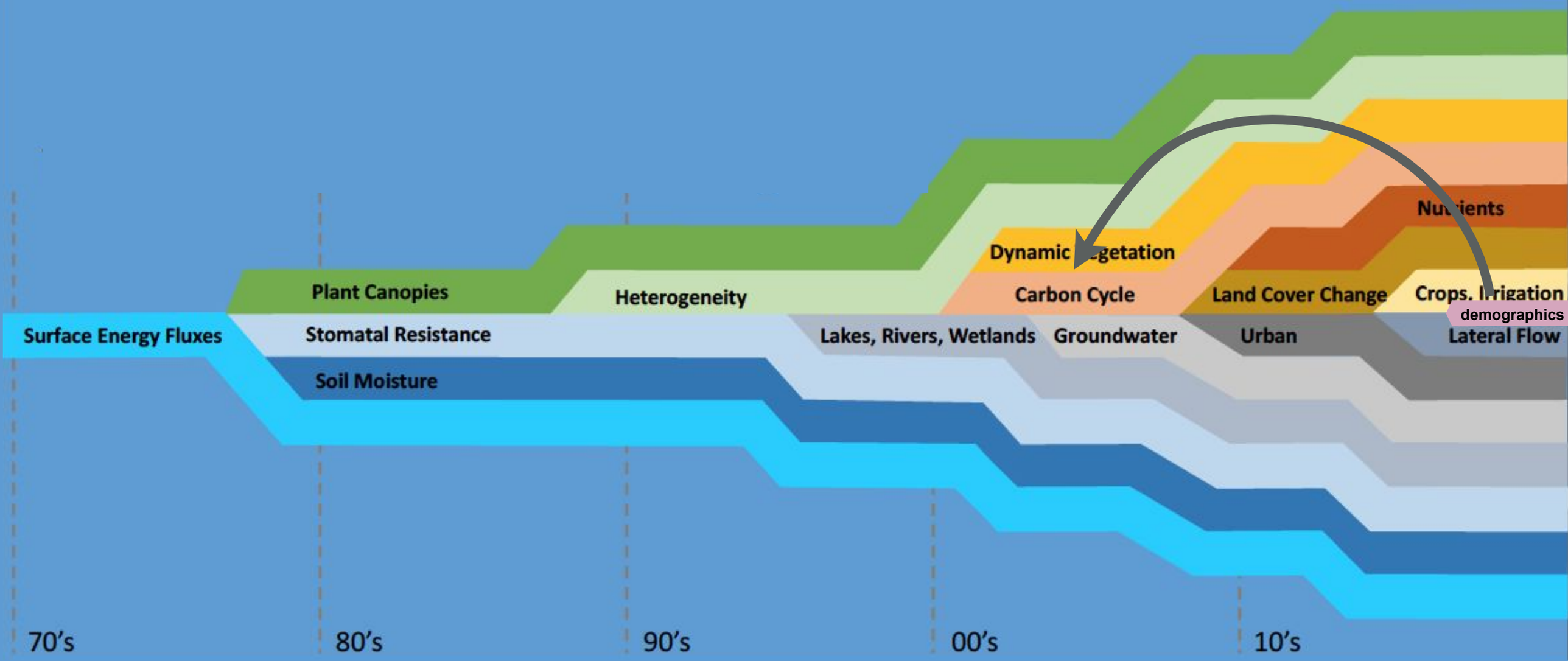
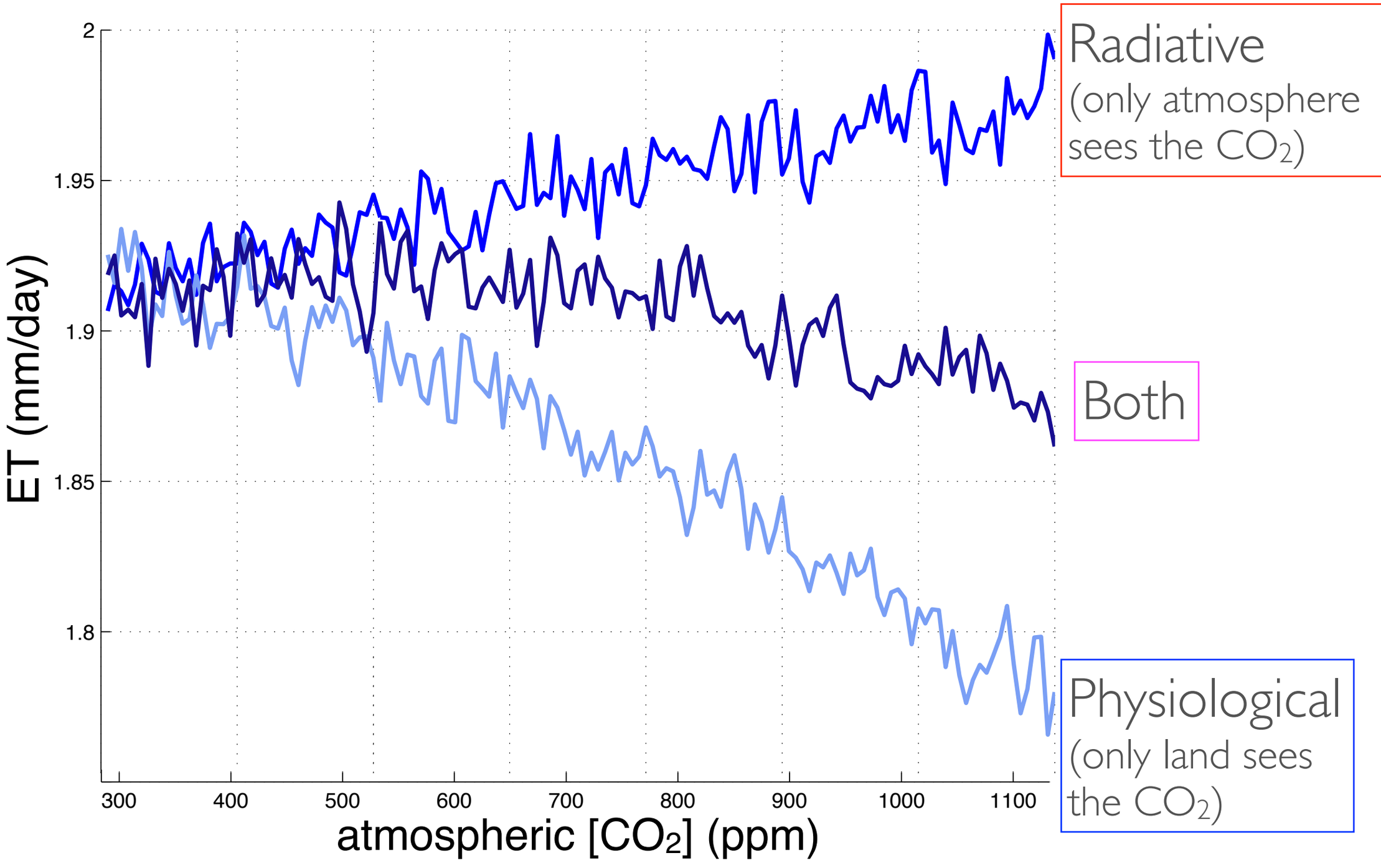


image: Rosie Fisher

We can use simulation experiments that isolate factors

i.e. Radiative vs. Physiological



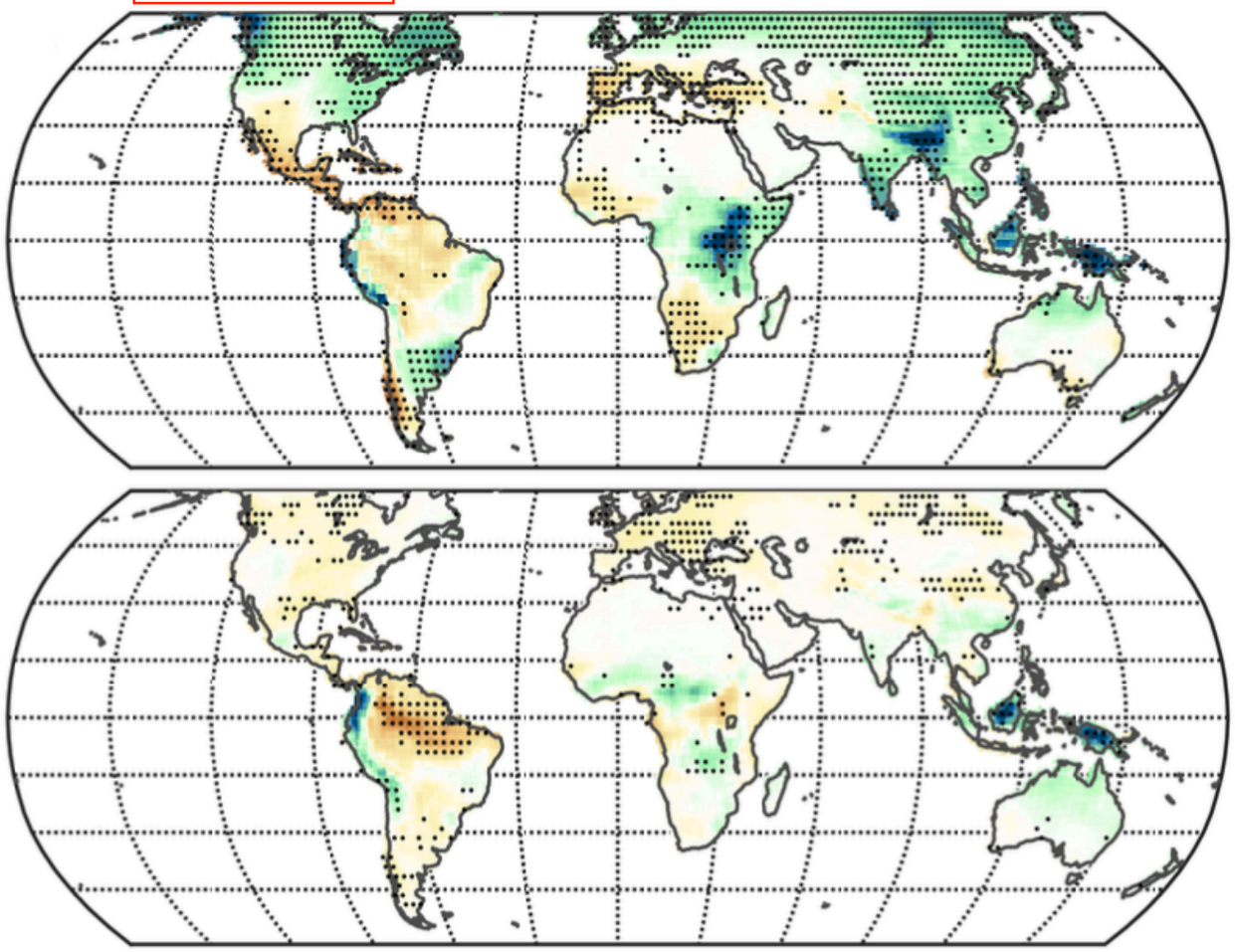
Multimodel mean for land area 45S to 45N

Swann et al. 2016 *PNAS*

Tropical Precipitation has a big signal from plants!

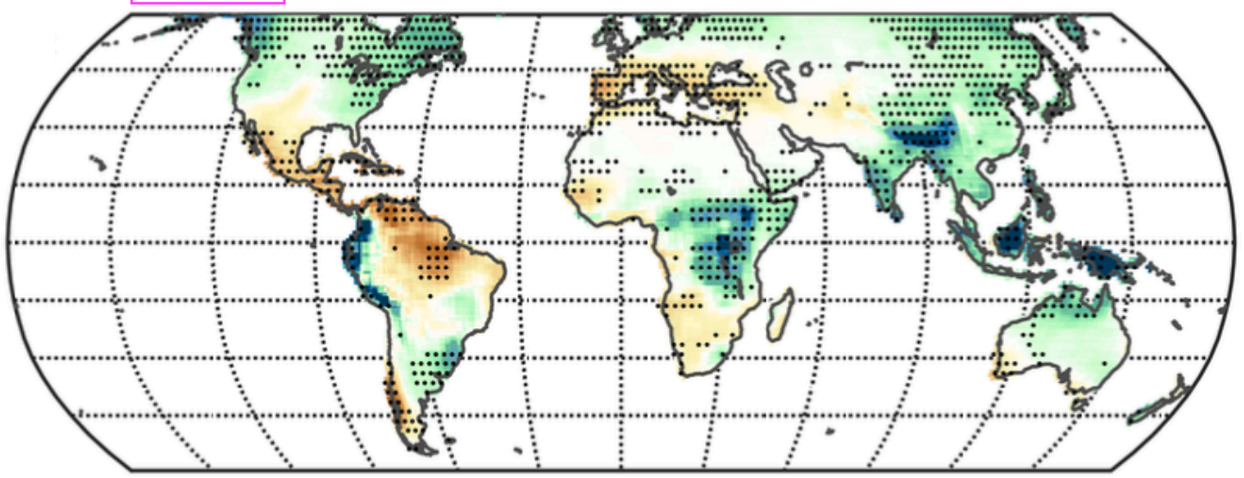
And it's all local to each continent, not due to circulation

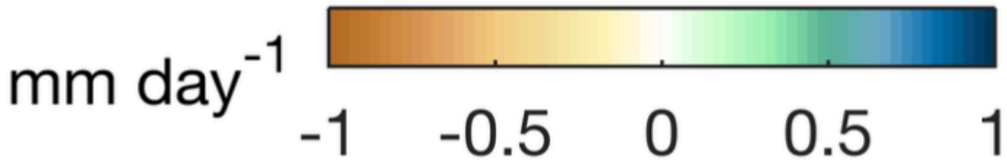
Radiative



Physiological

Both

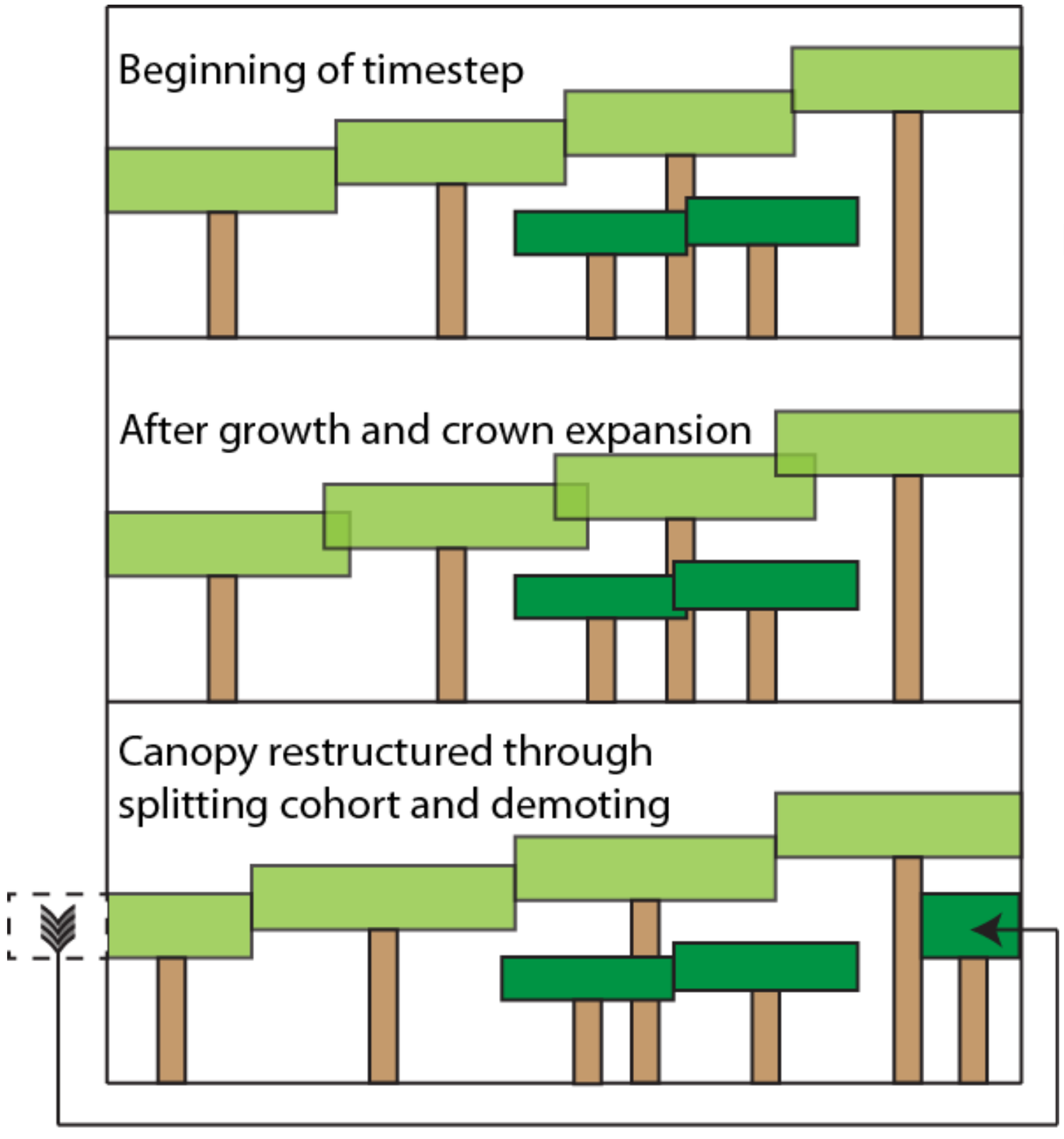




Kooperman et al. *Nat. Climate Change, accepted*

Plant Demographic models capture heterogeneity

FATES model



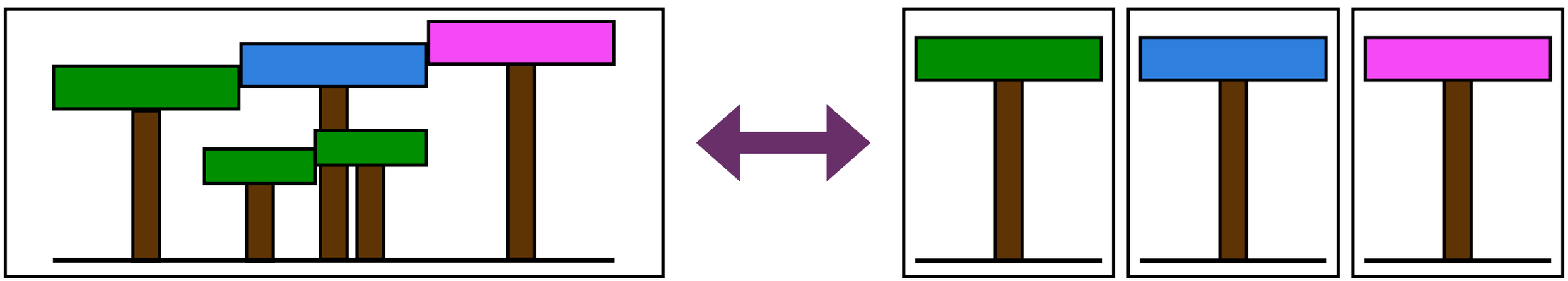
And that is really exciting!

Charlie Koven

To understand what all the complexity is doing, we have to be able to remove it

ED/FATES-like

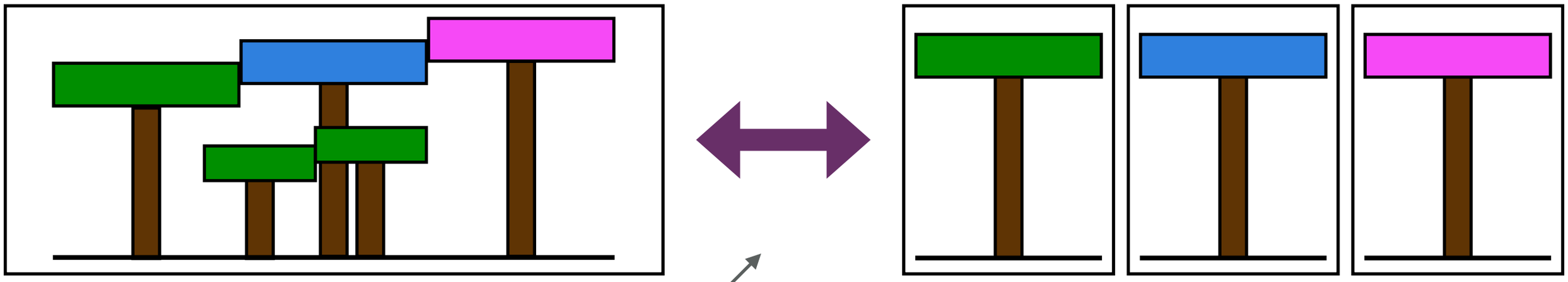
CLM-like



It would be *most* useful to scale complexity up and down within a single model

ED/FATES-like

CLM-like

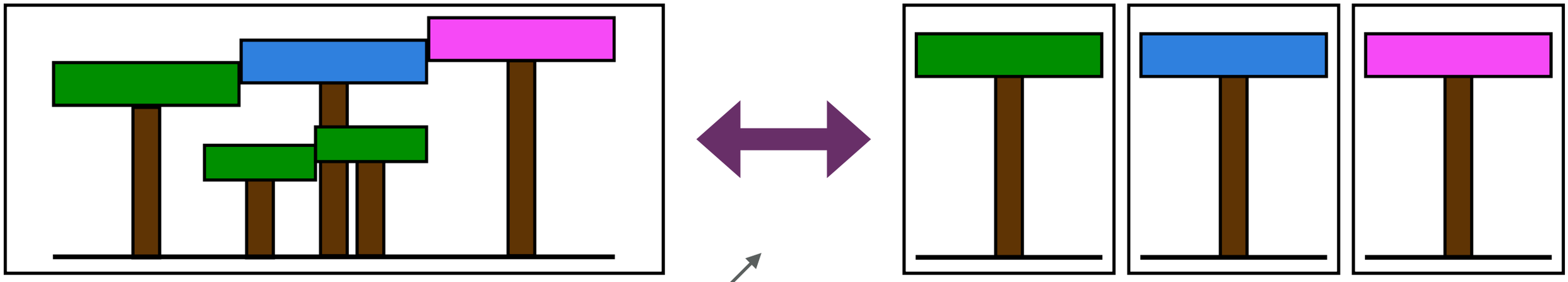


Multiple dimensions on which to allow more or less complexity in the demographics

It would be most useful to scale complexity up and down within a single model

ED/FATES-like

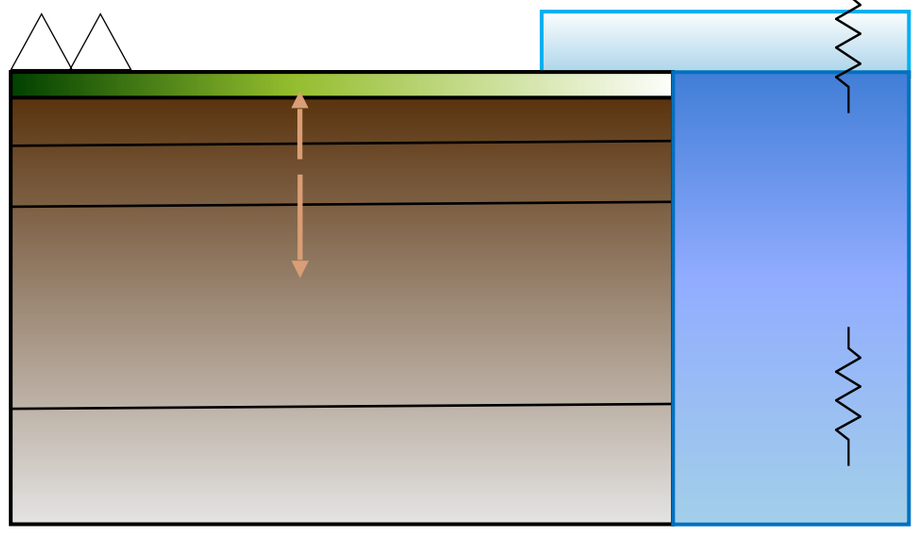
CLM-like



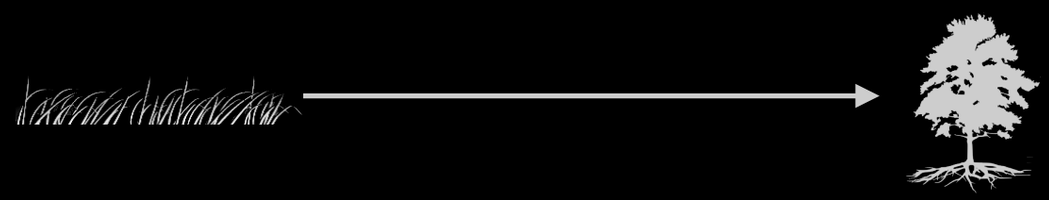
Multiple dimensions on which to allow more or less complexity

?

Simple



My argument today:



Simpler models help us understand ***why***

An ideal ESM would have many options for land surface complexity that are self-consistent