Terrestrial evaporation: local warming vs. global cooling

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With:

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Land ≠ Ocean

Differences in:

- Capacity of the land to store water
- Heat capacity
- Topography
- Surface properties

and more!

The ocean effectively has unlimited water:
evaporation is limited by the evaporative demand of the atmosphere

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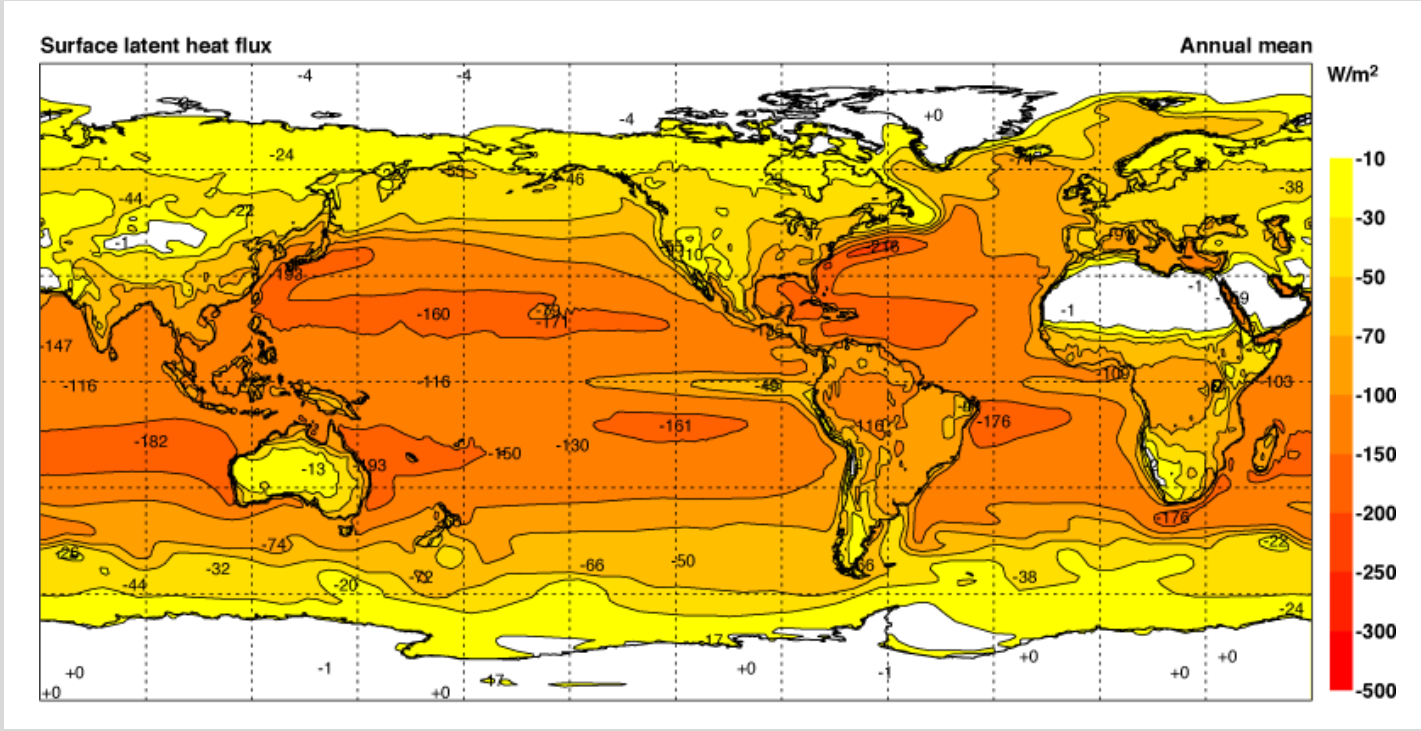
Annual Mean Surface Latent Heat Flux



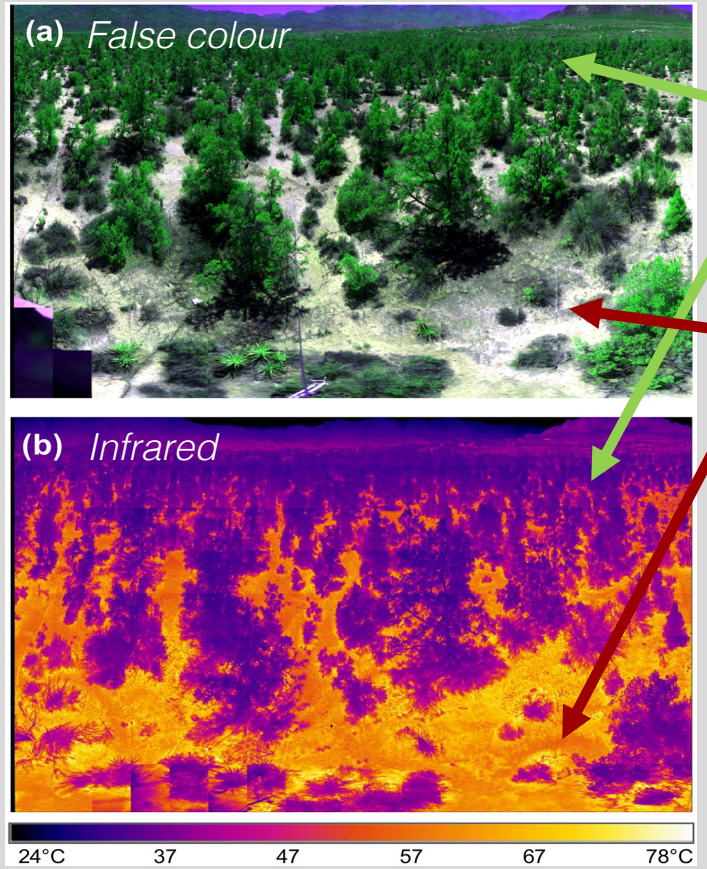
ECMWF

Terrestrial evaporation directly cools the land surface

↑ Latent heat flux

↑ Evaporative cooling

↓ Surface temperature



leaves (cool)

ground (hot)

$LW^{\uparrow} = \sigma T_s^4$

Still et al. 2019: Pinyon-Juniper woodland in southern California

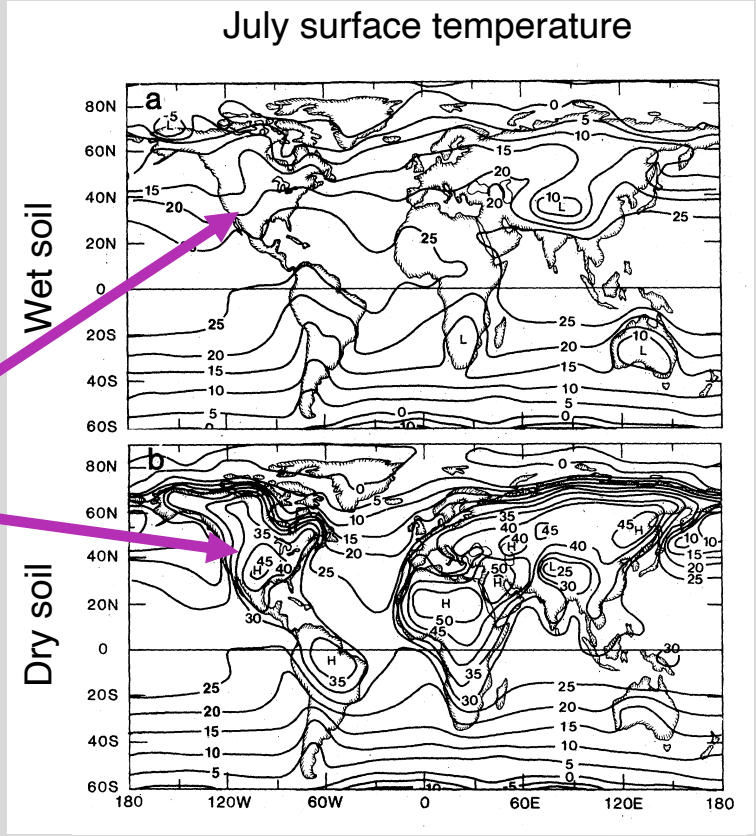
↓ land evaporation in models = warmer land (and ocean)

↓ Latent heat flux

↓ Evaporative cooling

↑ Surface temperature

Land is hotter if it
can't evaporatively cool



Shukla & Mintz 1982

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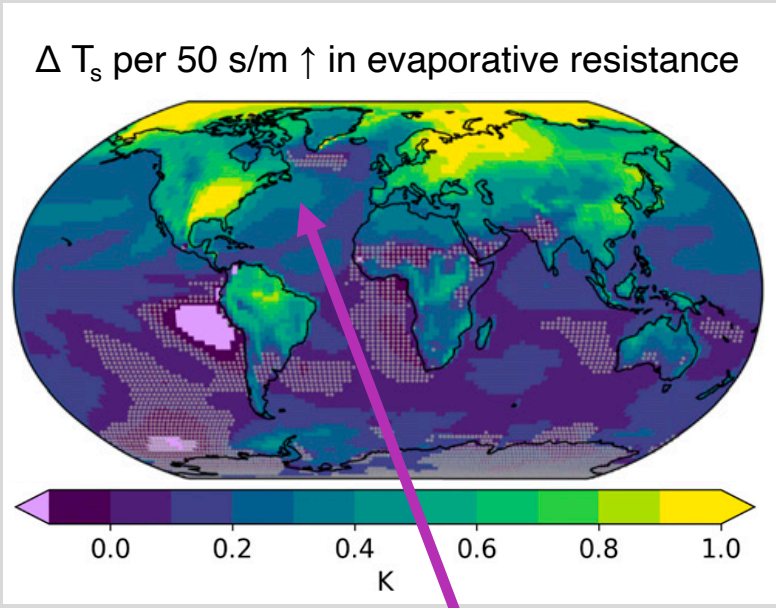
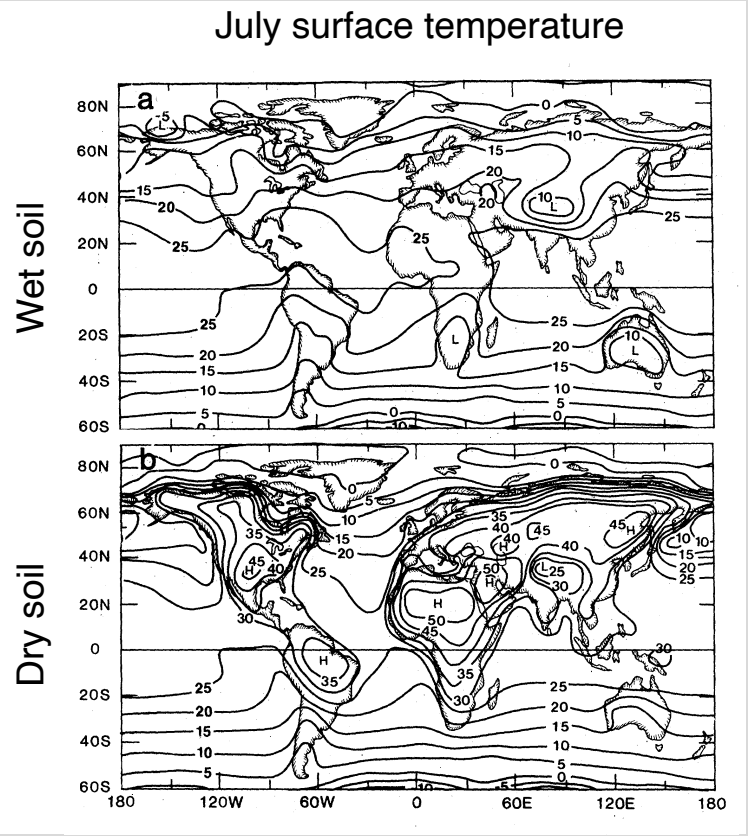


Laguë et al. 2019

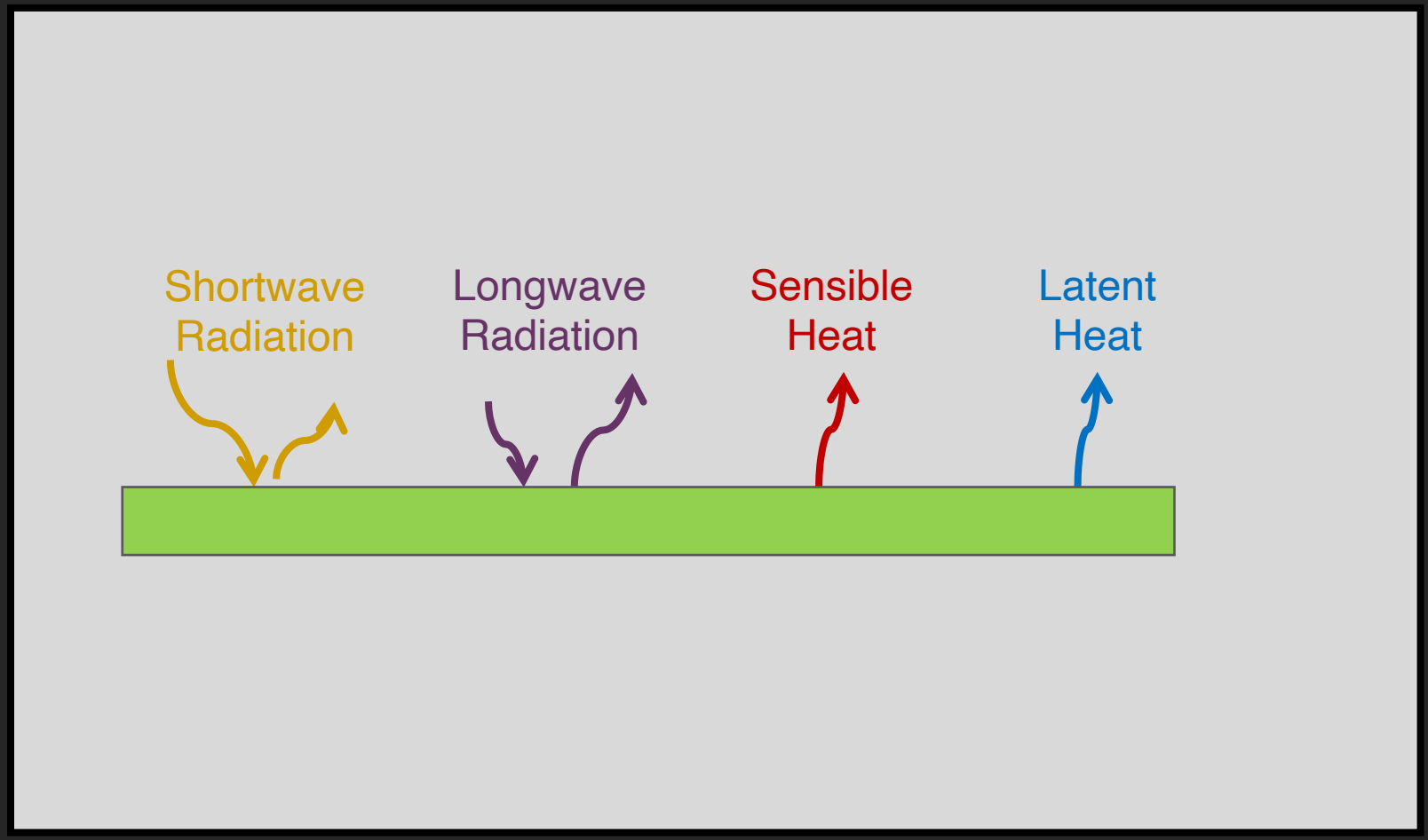
Warming can "drift" out over the ocean



Shukla & Mintz 1982

↓ land evaporation = warmer land (form surface energy budget)

- Direct result of repartitioning the the surface energy budget
- As such, we might not expect it to have anything to do with continental configuration…



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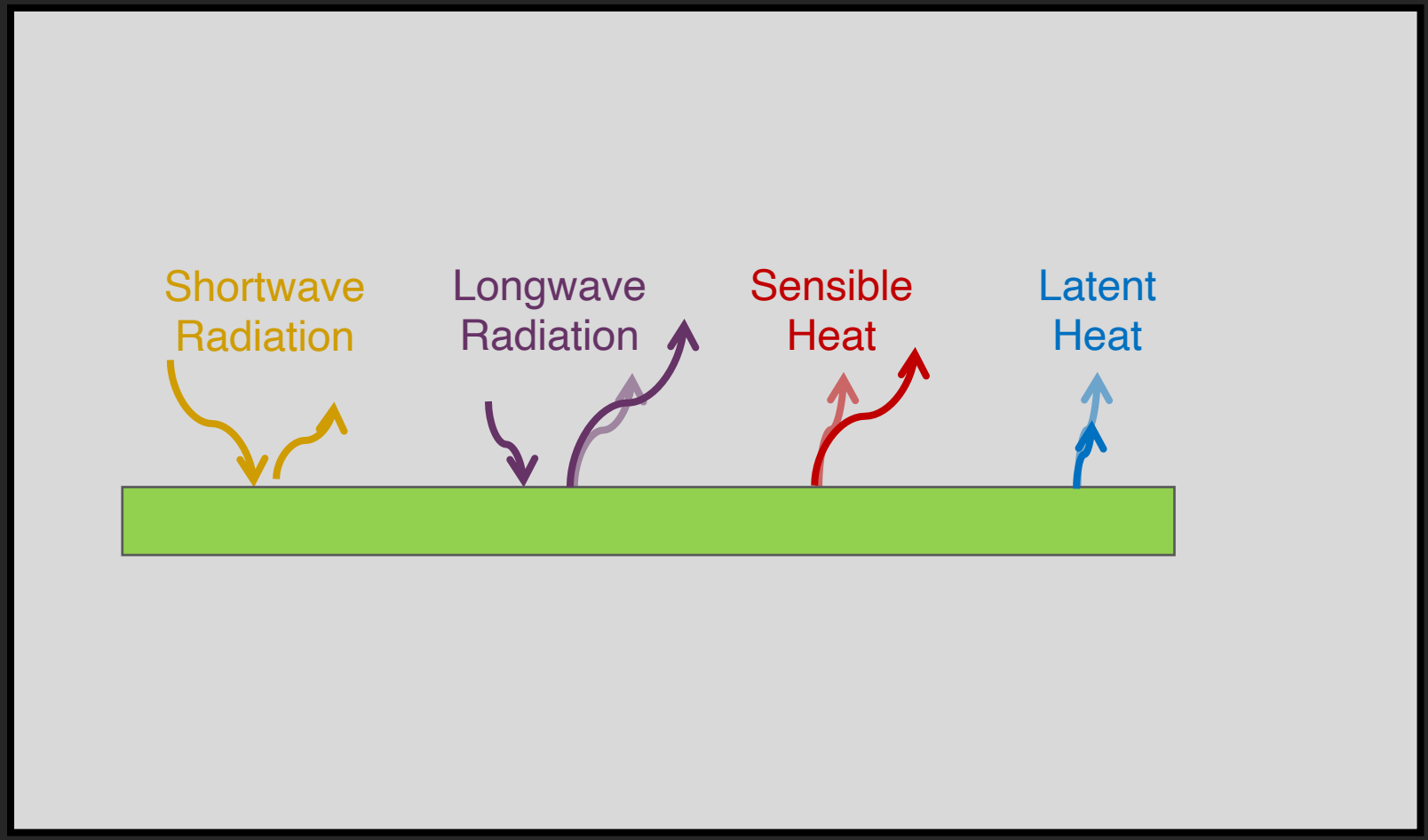
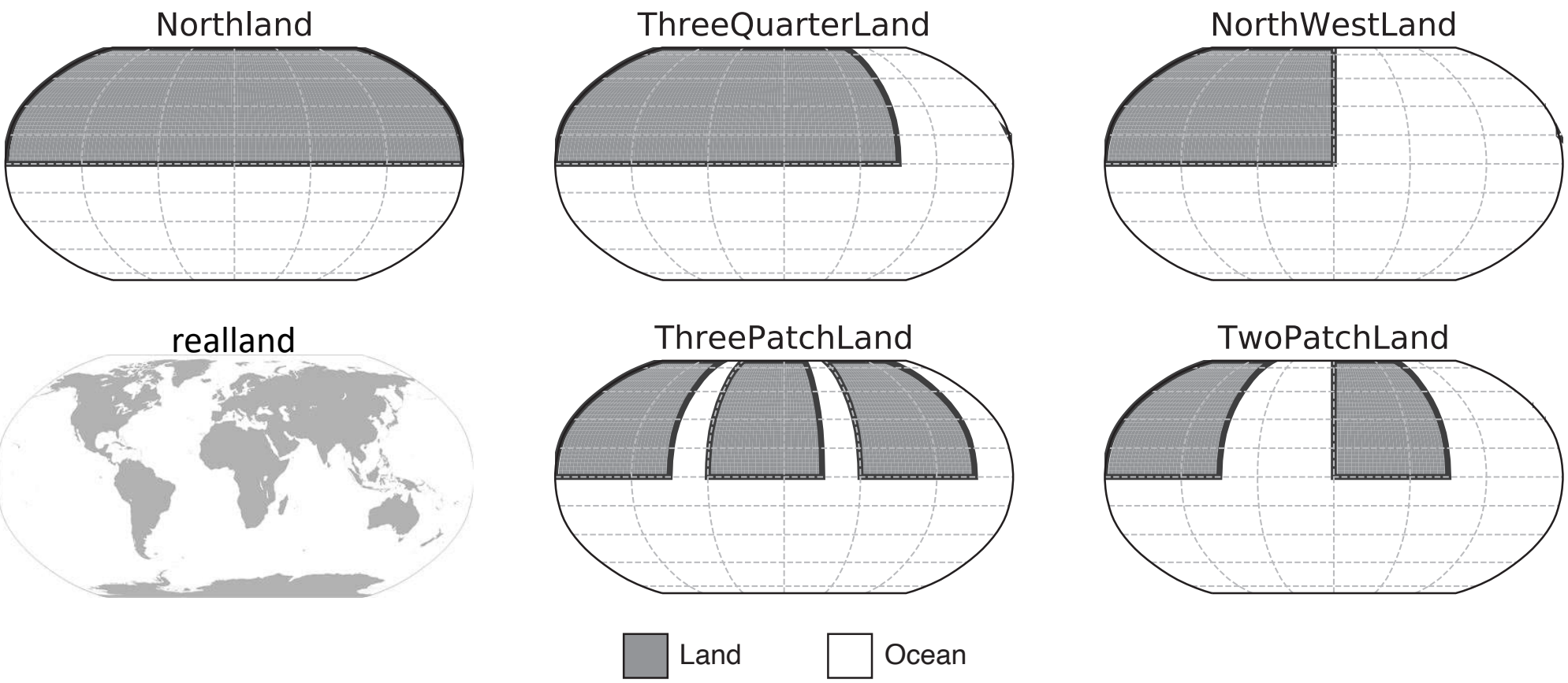


Suppress evaporation in 6 different continental configurations

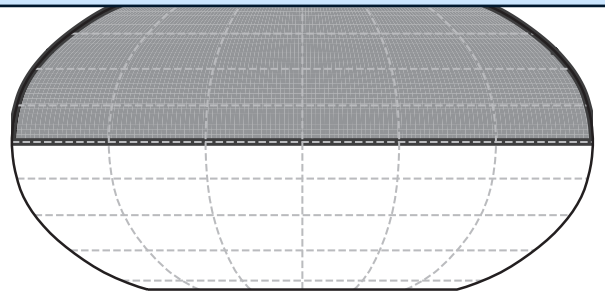
See what happens to surface temperatures

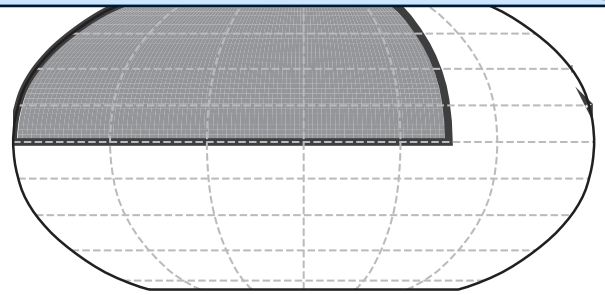


Suppress evaporation in 6 different continental configurations

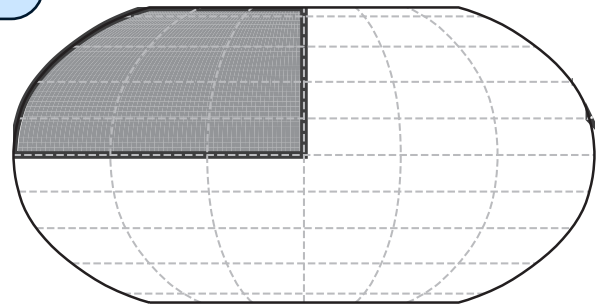
See what happens to surface temperatures

Make the land “bucket” very tiny – near-zero terrestrial water storage… like a well drained paved parking lot

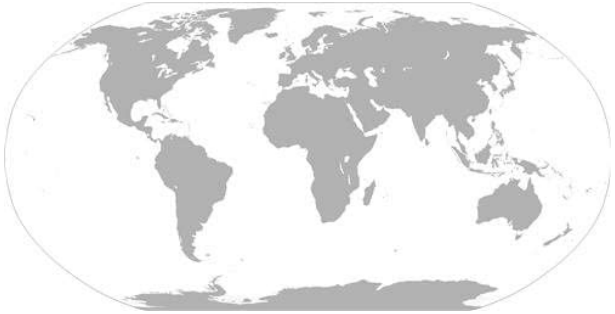




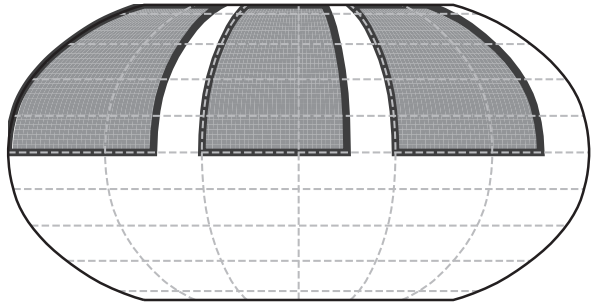
NorthWestLand



realland



ThreePatchLand



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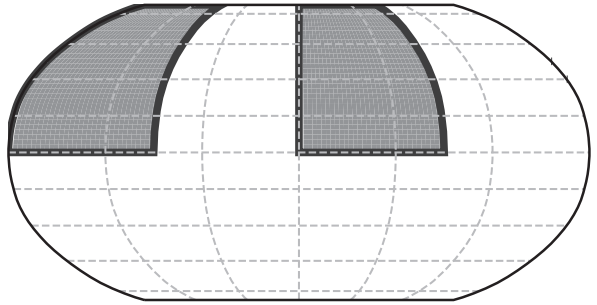
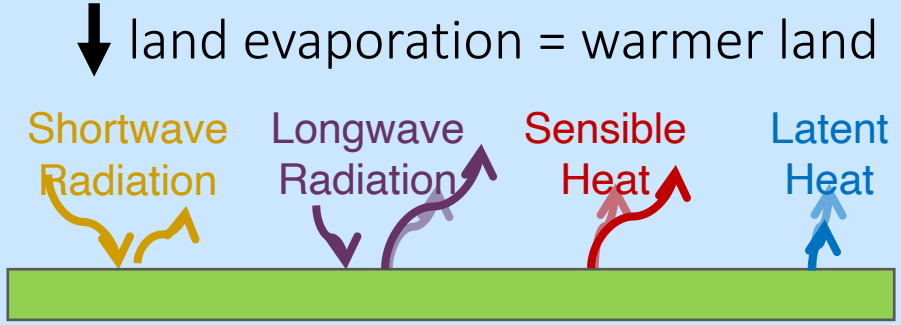


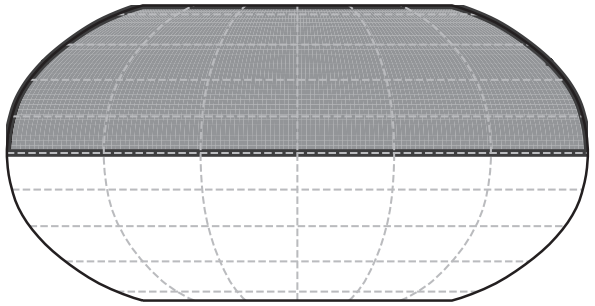
Isca idealized climate model
Idealized general circulation model, slab ocean
Simple land (Manabe bucket model)

Super easy to move continents around
1 experiment with normal bucket land
1 experiment with tiny bucket land

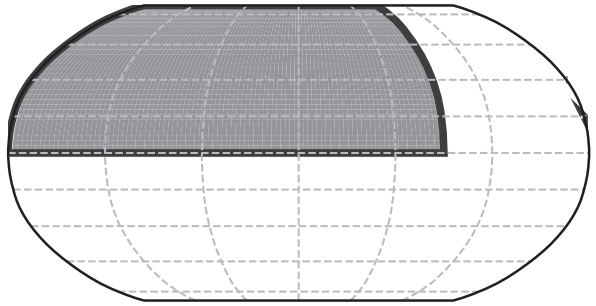
If all we care about is the surface energy budget, this should warm



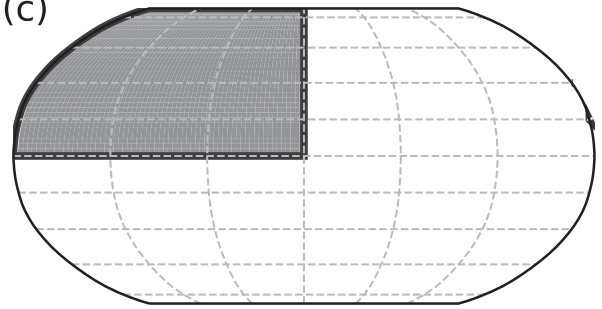
Northland



ThreeQuarterLand



(c) NorthWestLand



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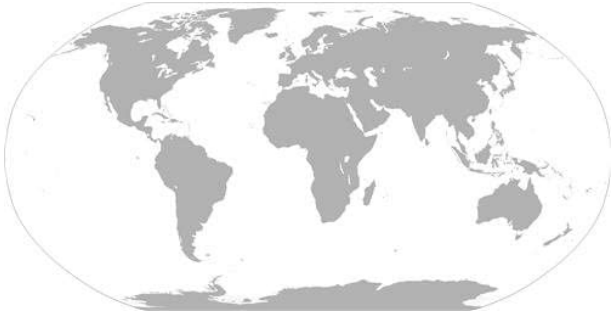

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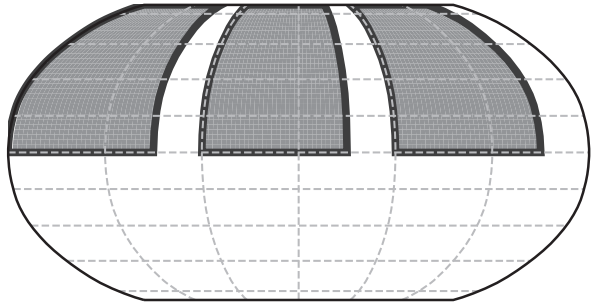

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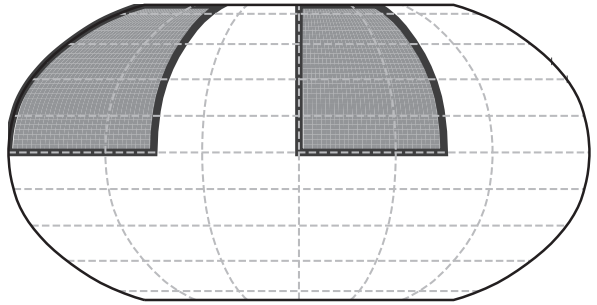

Isca idealized climate model
Idealized general circulation model, slab ocean
Simple land (Manabe bucket model)

Super easy to move continents around
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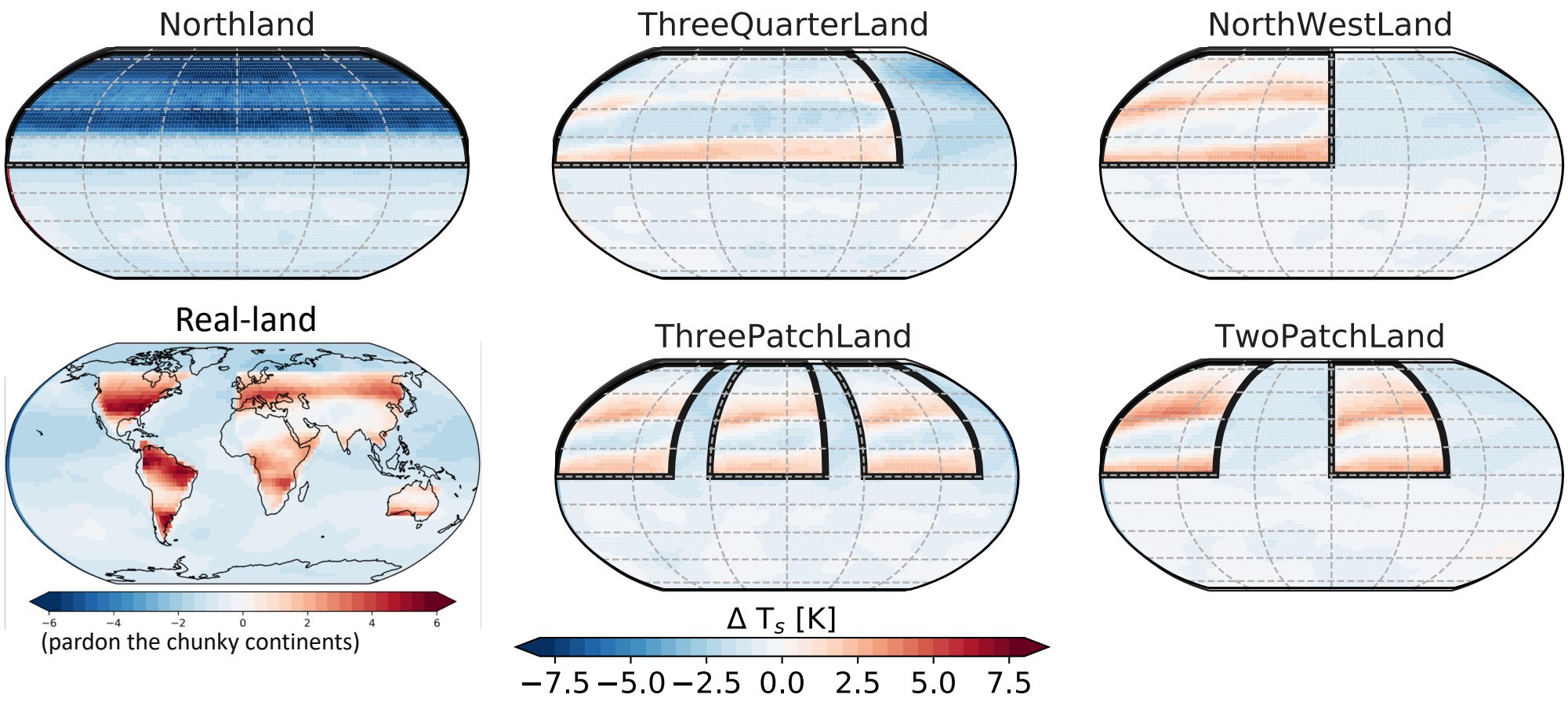
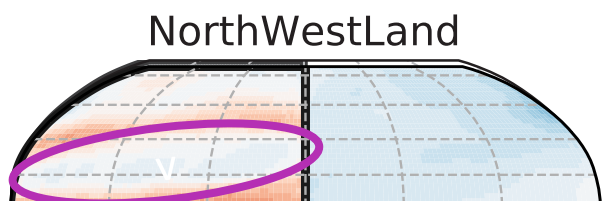
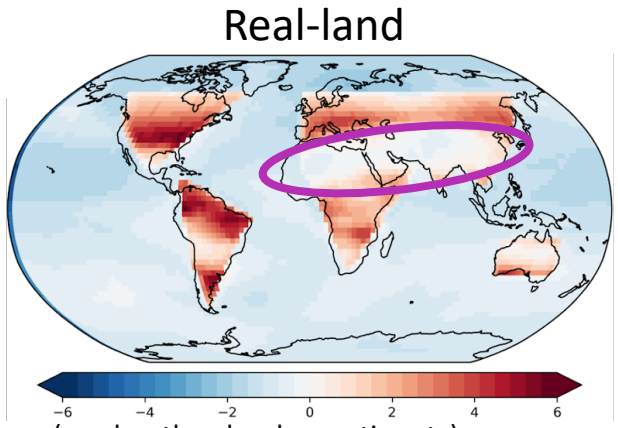
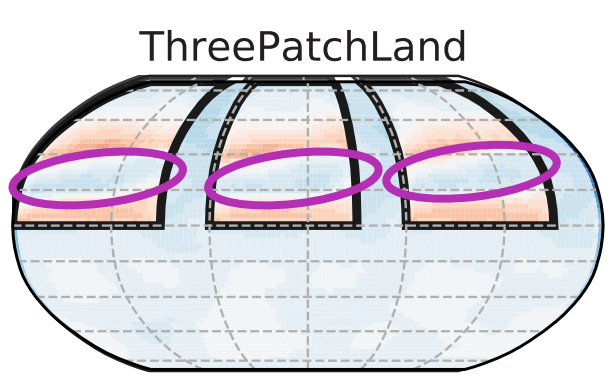
Suppressing land evaporation warms (red) *some* places, in *some* continental configurations… otherwise large-scale **cooling**

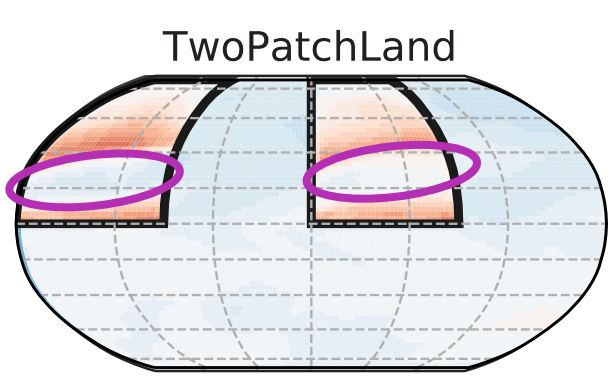


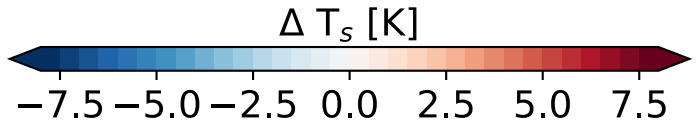
Subtropical deserts have no warming effect, just large-scale cooling



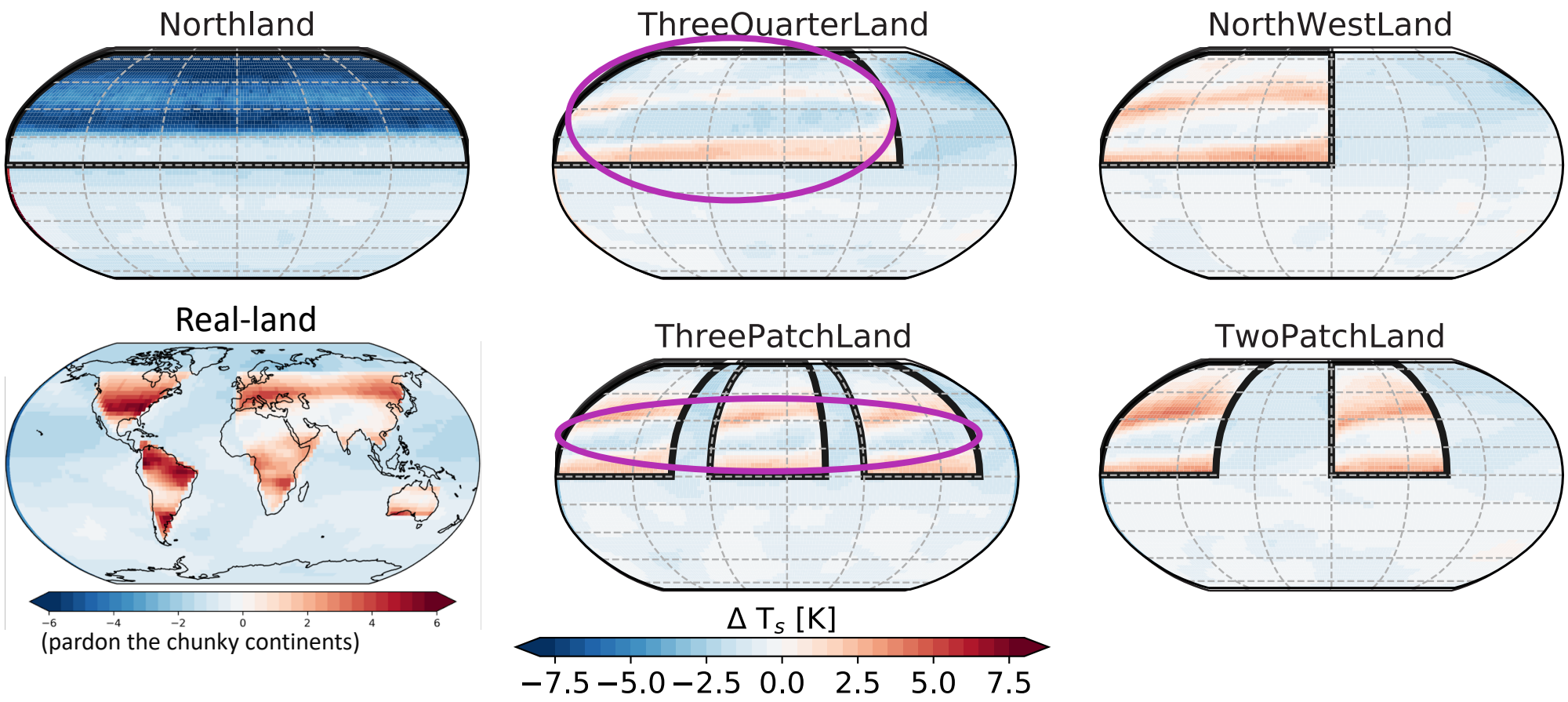




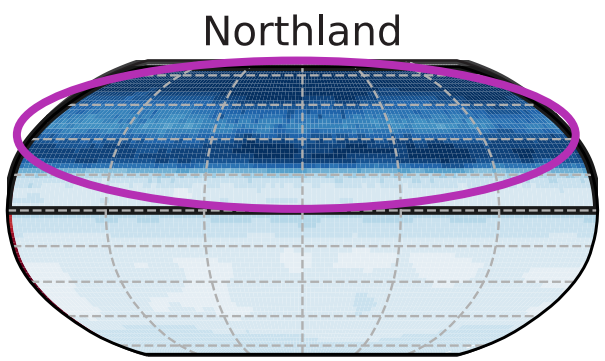


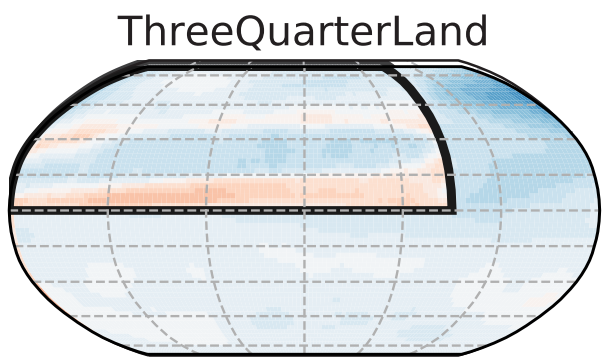


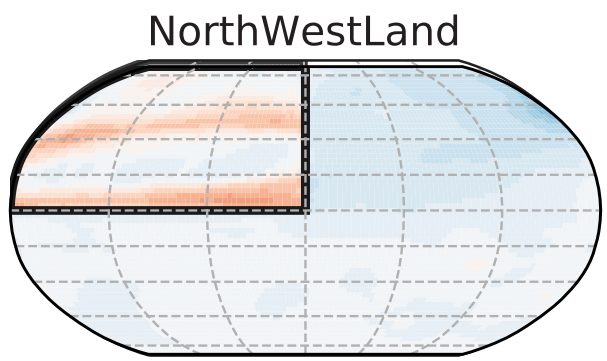
Bigger continents have larger dry/desert areas, where evaporation is always zero… so making it harder to evaporate doesn't lead to any local warming (zero to start, zero to end…)

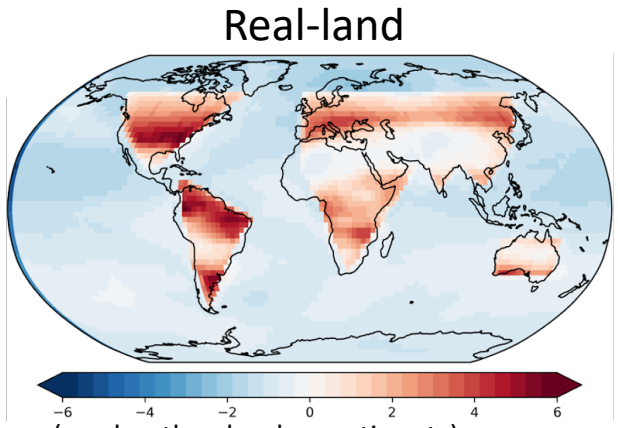


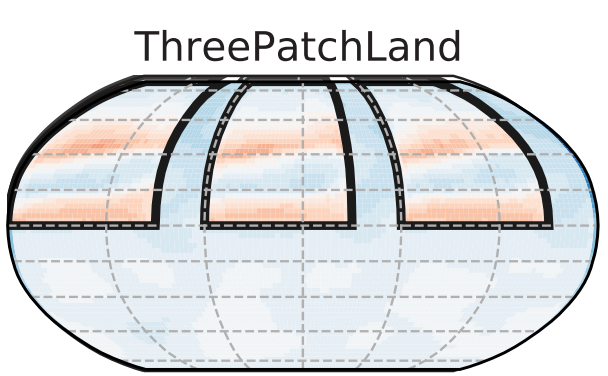
Unlike the other continental configurations, Northland shows a huge cooling signal everywhere

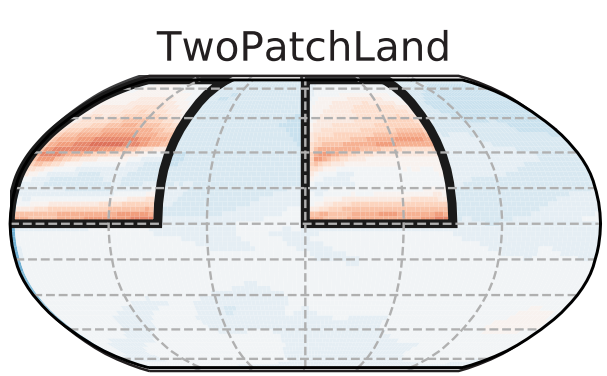


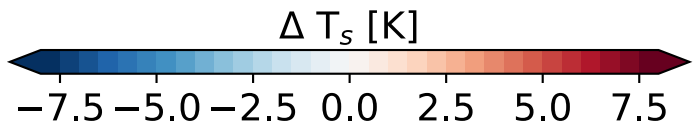




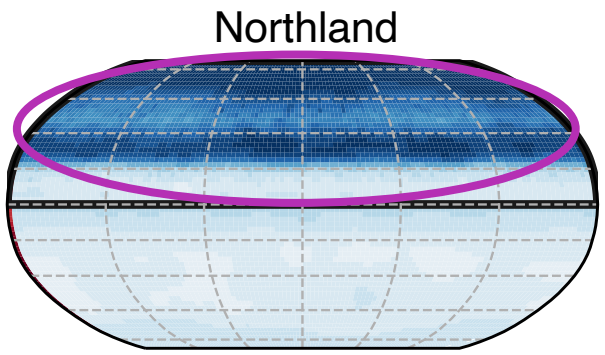








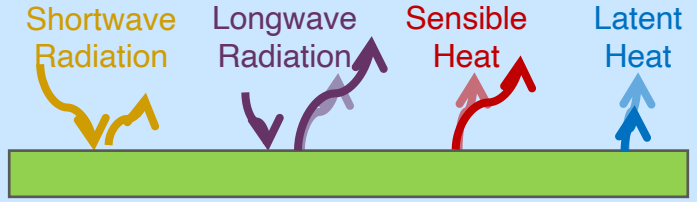
Why is Northland cooling when evaporation decreases?



Obviously not all we care about

If all we care about is the surface energy budget, less evap = warming

↓ land evaporation = warmer land



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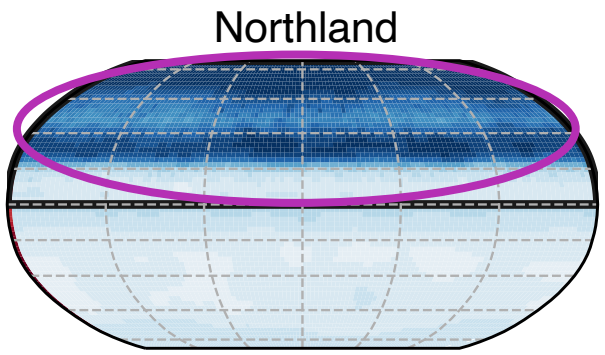

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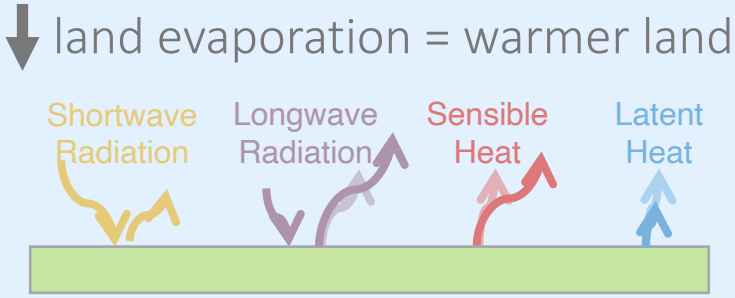

BUT water vapour is also a fantastic greenhouse gas

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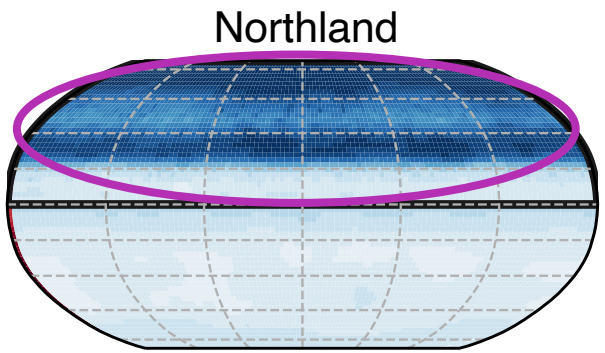

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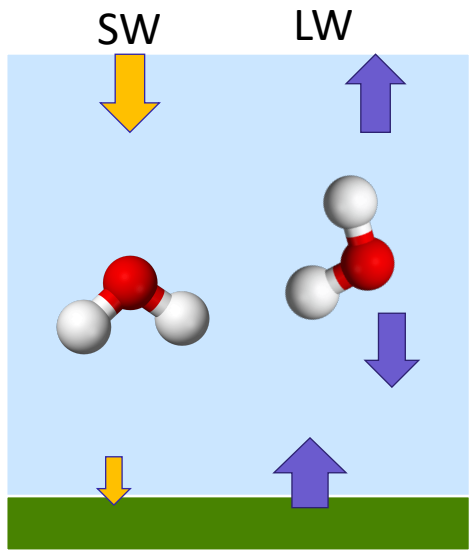
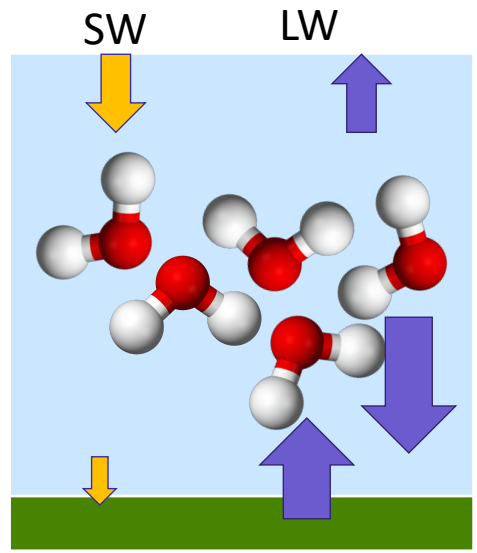


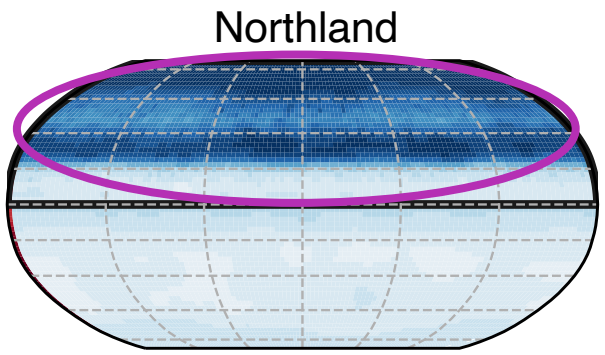
Little water vapour
= cooler surface

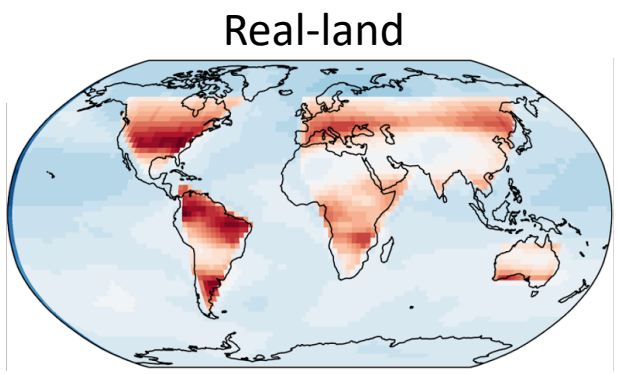


Lots of water vapour
= warmer surface

~ ½ of the modern greenhouse effect (Sherwood et al 2018)

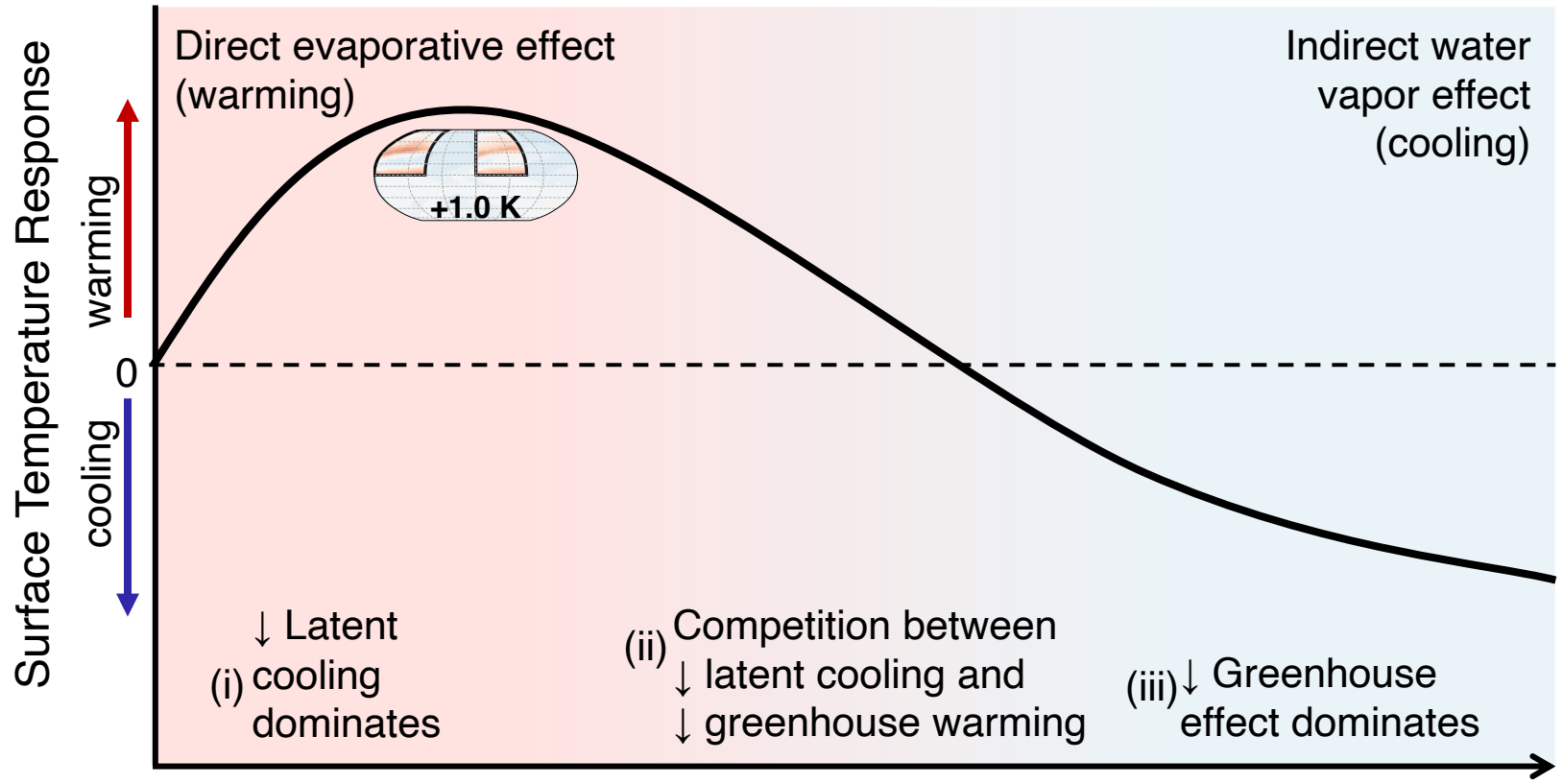
Why is Northland cooling when evaporation decreases?

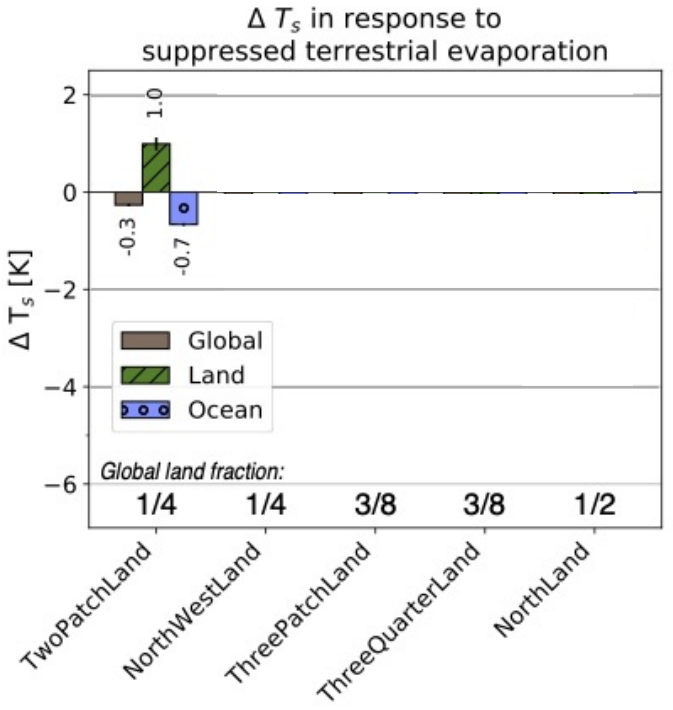




- In the present climate, there is plenty of ocean at every latitude, so it is hard to deplete the atmosphere of water vapour
- In Northland, there is no infinite water source in the NH
- Collapse the water vapour greenhouse = big cooling signal

Balance of local warming vs global cooling from ↓ land evaporation depends on total land area, contiguous continent size, and location





Laguë et al. 2021

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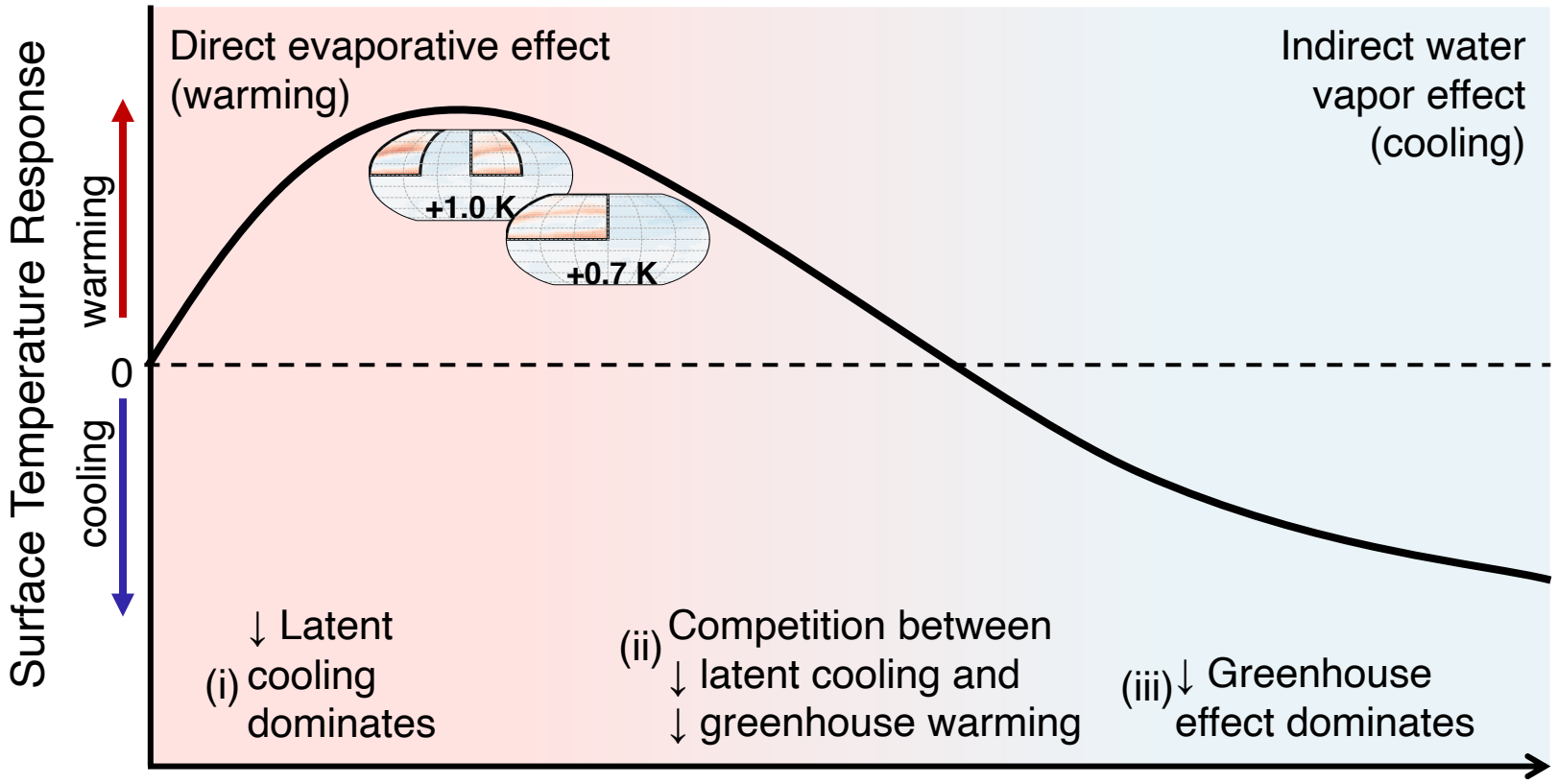

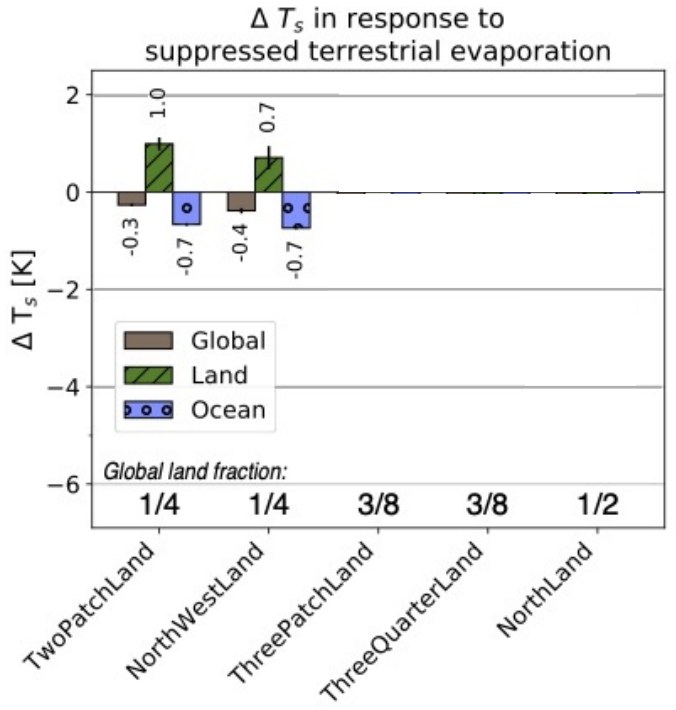

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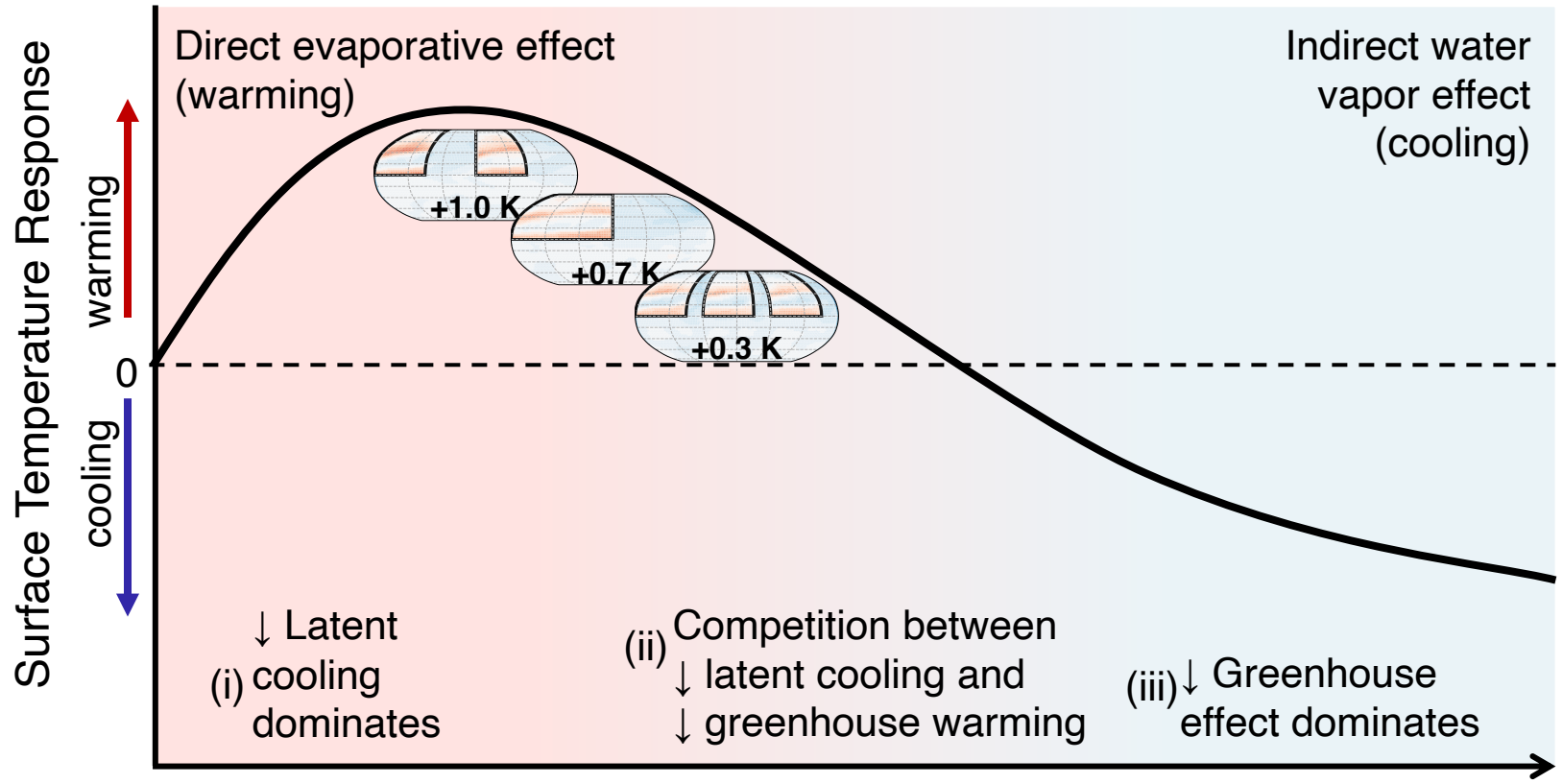

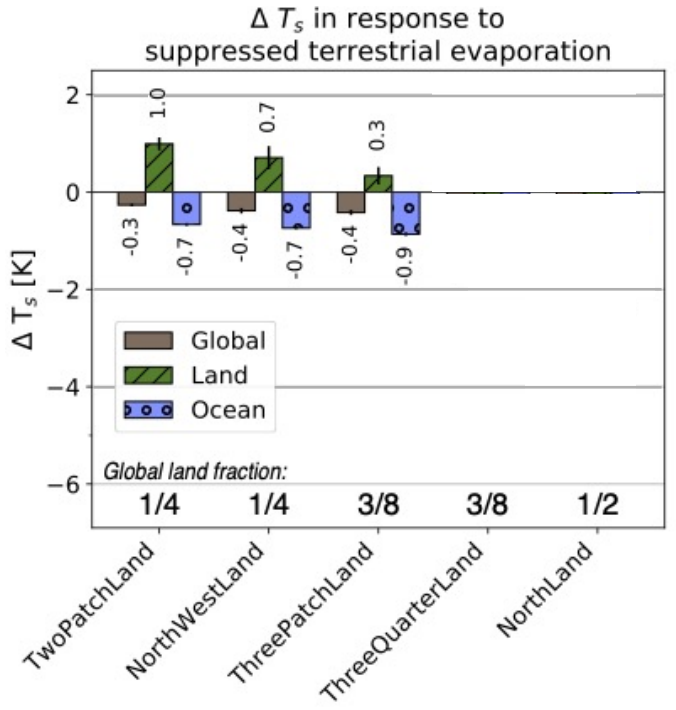

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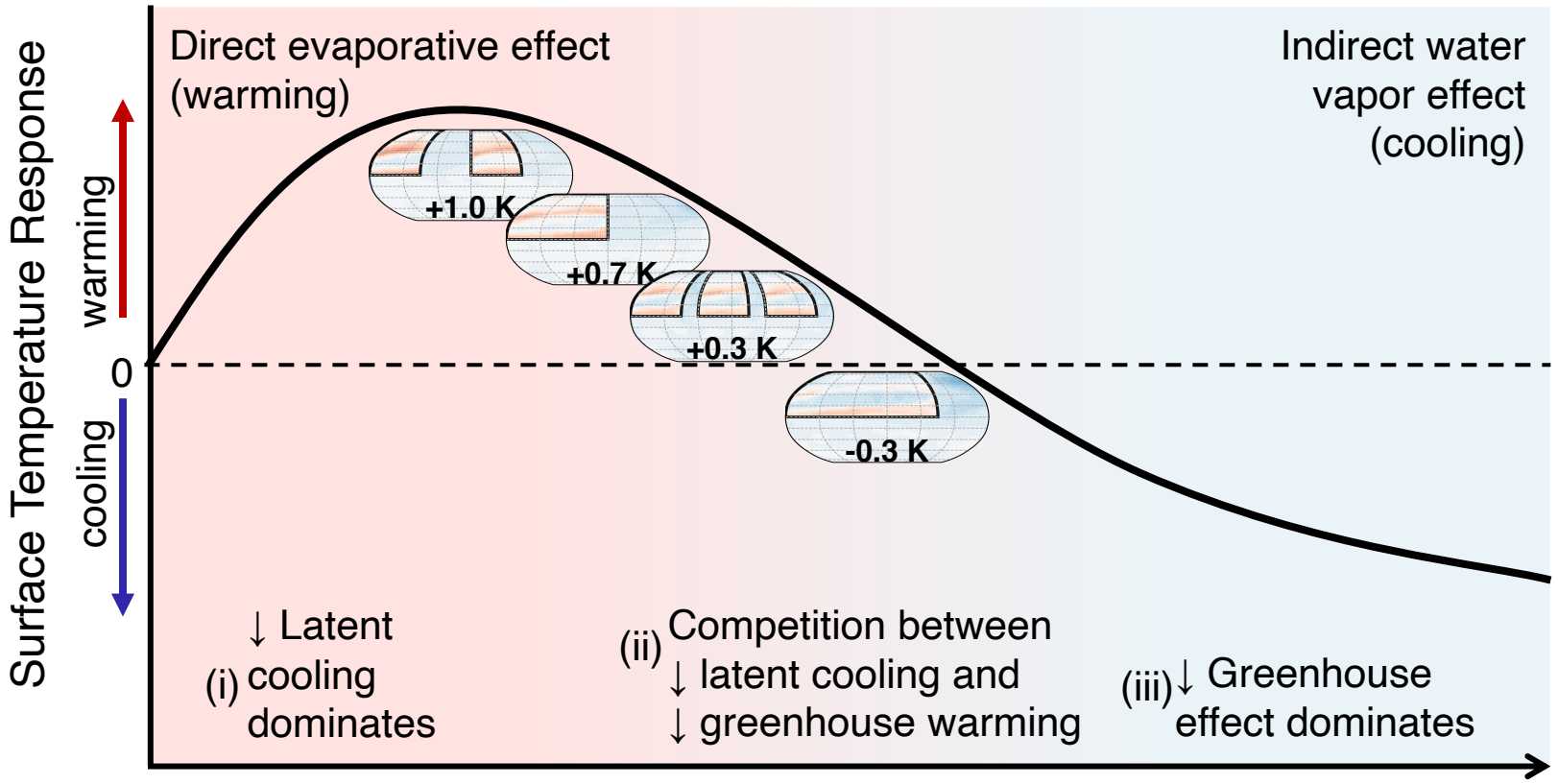

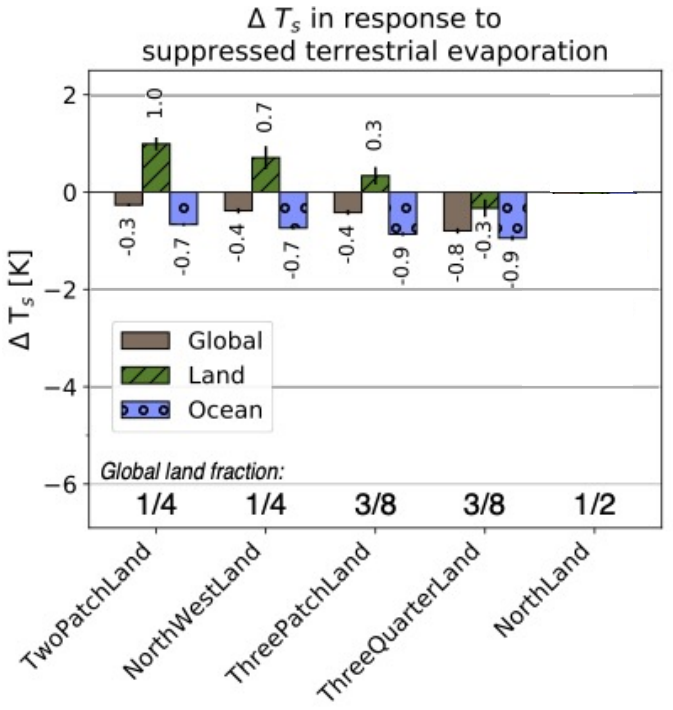

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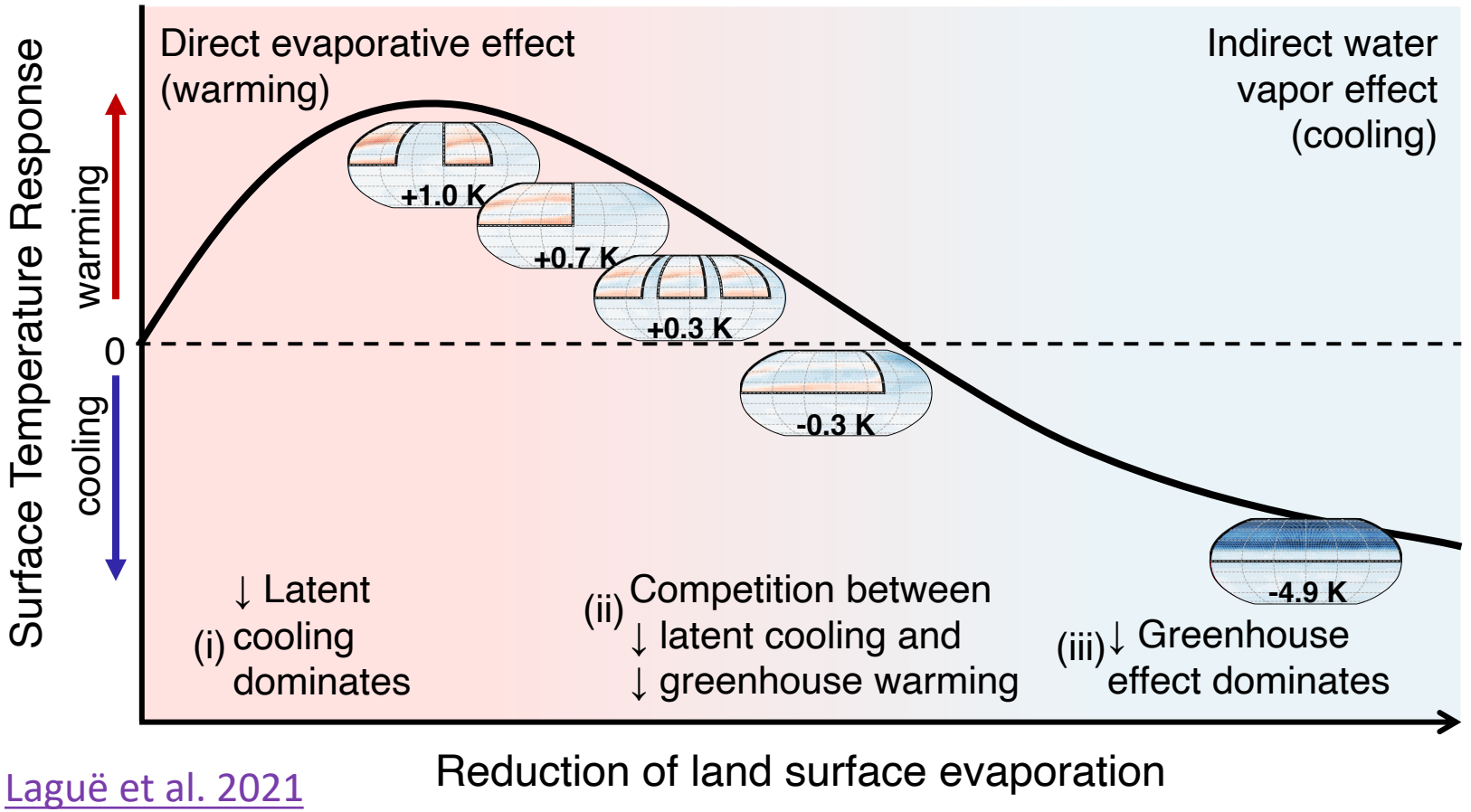

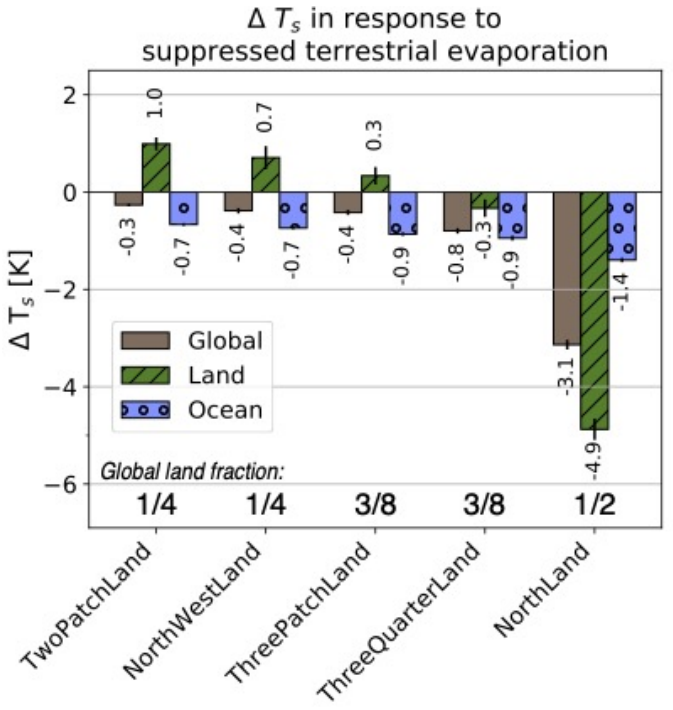

Laguë et al. 2021

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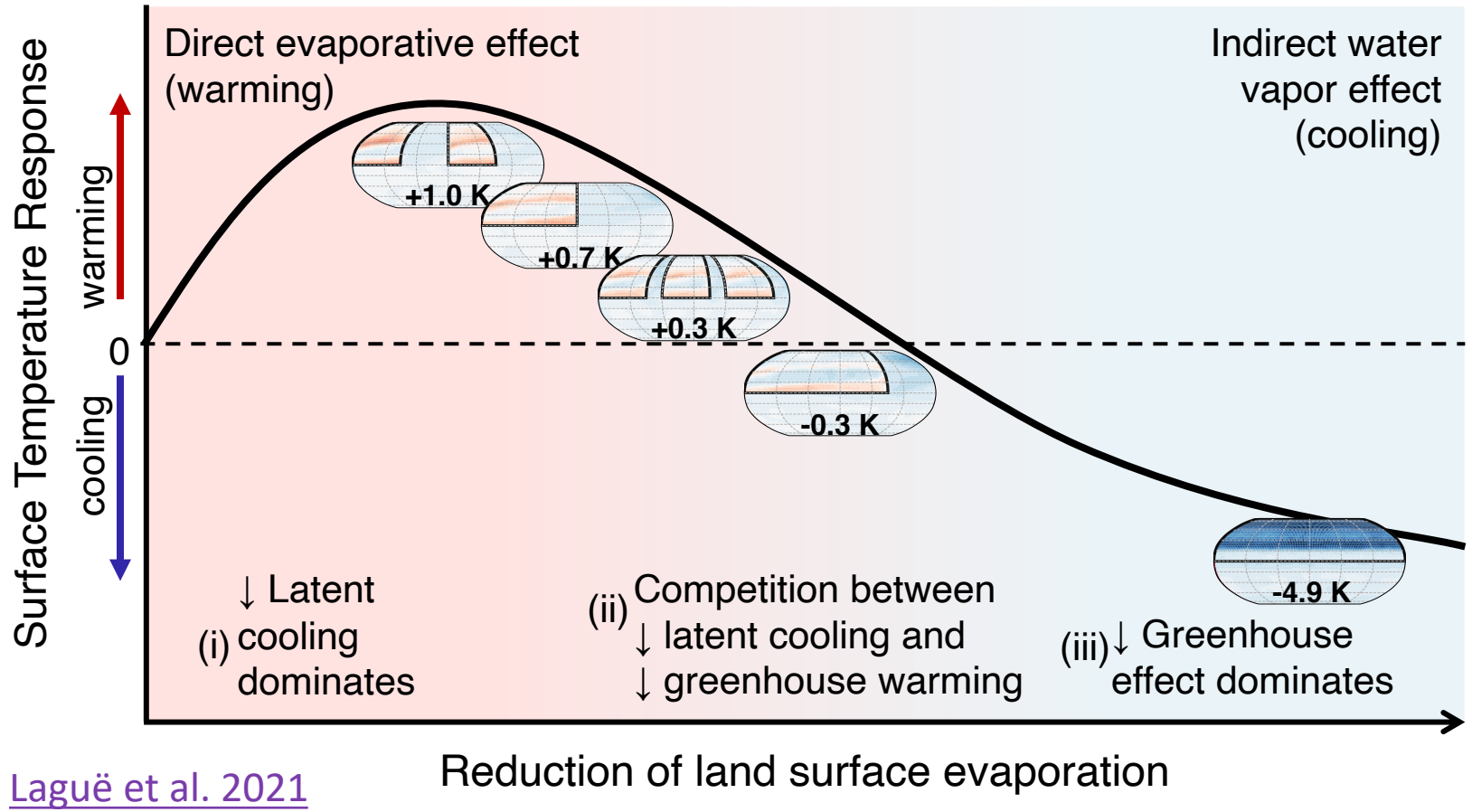
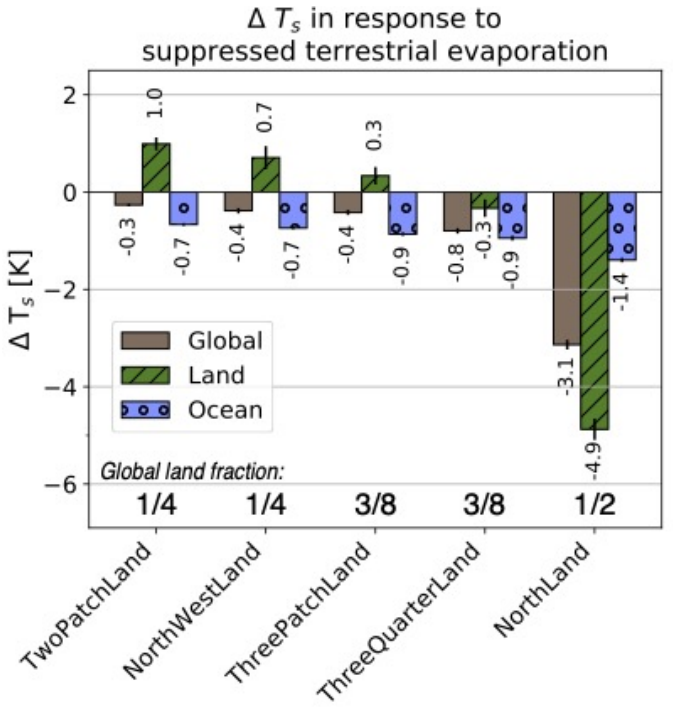
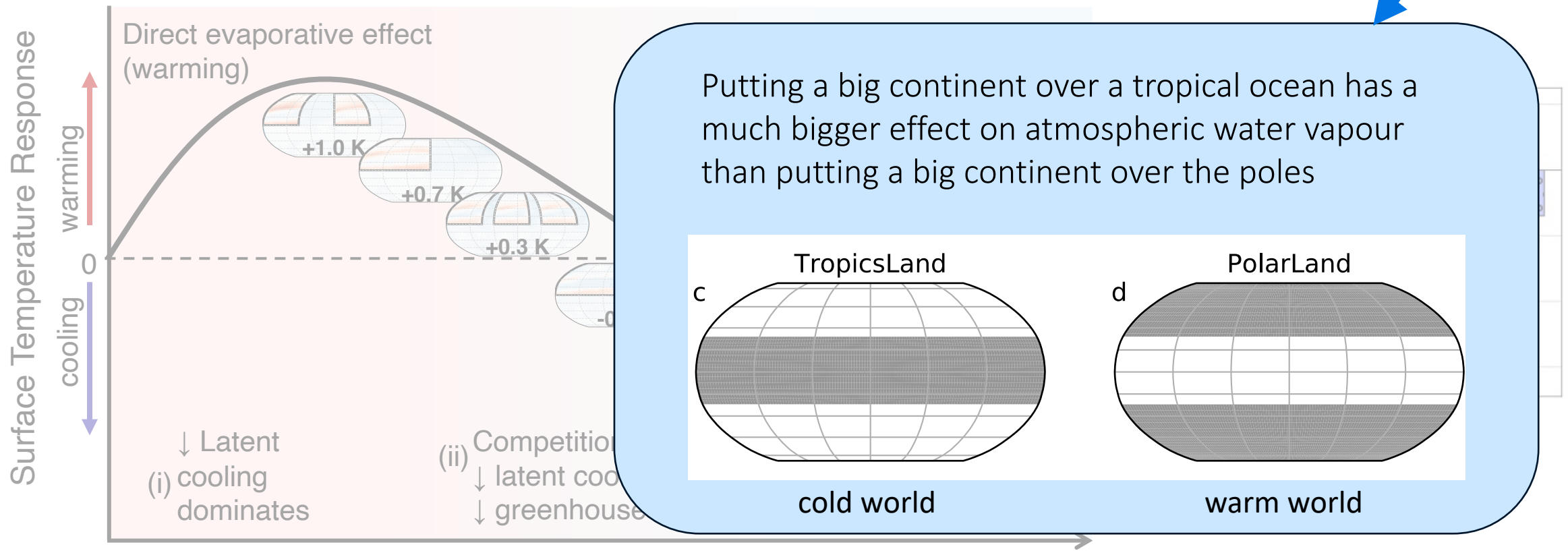


Laguë et al. 2021



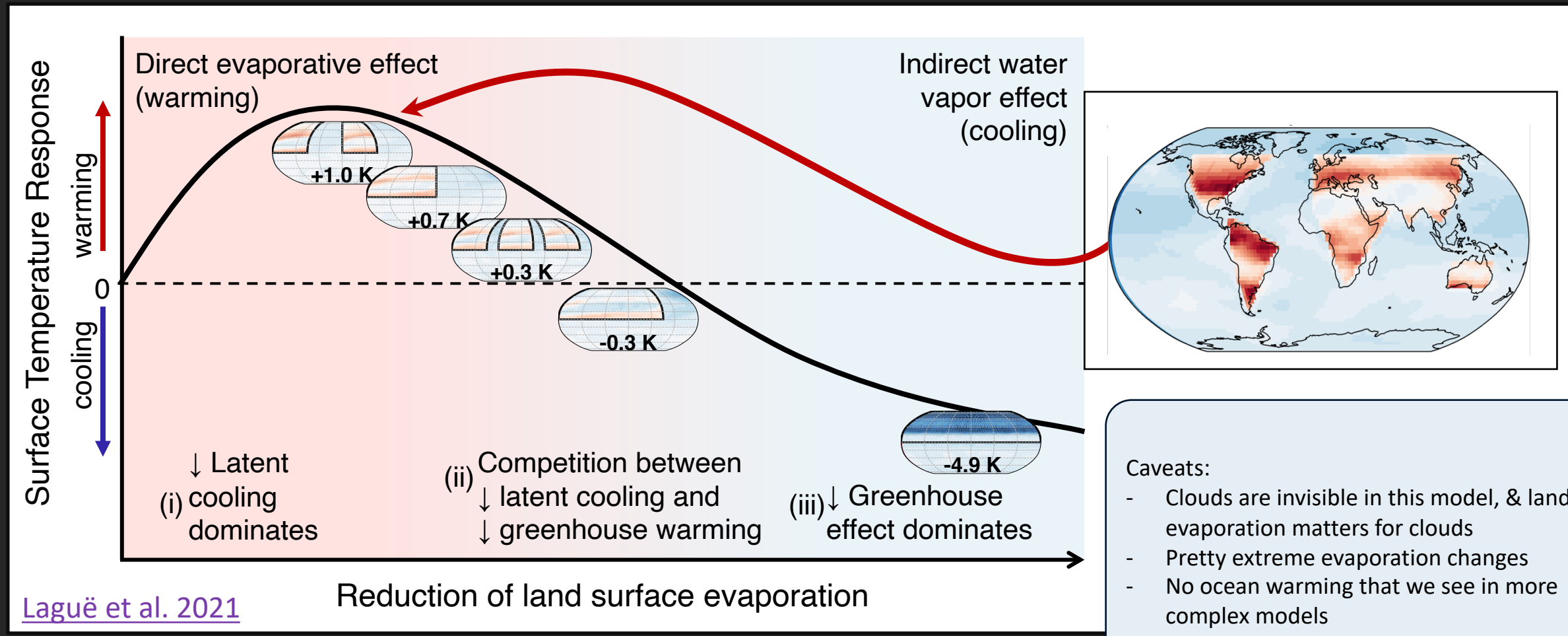
Colder air from ↓ water vapour = less LW ↓ over oceans

Balance of local warming vs global cooling from ↓ land evaporation depends on total land area, contiguous continent size, and **location**



Laguë et al. 2021

Real (modern) world sits somewhere to the left of this curve: plenty of ocean at every latitude keeps the atm from getting too depleted in water vapour



Laguë et al. 2021

Caveats:
- Clouds are invisible in this model, & land evaporation matters for clouds
- Pretty extreme evaporation changes
- No ocean warming that we see in more complex models

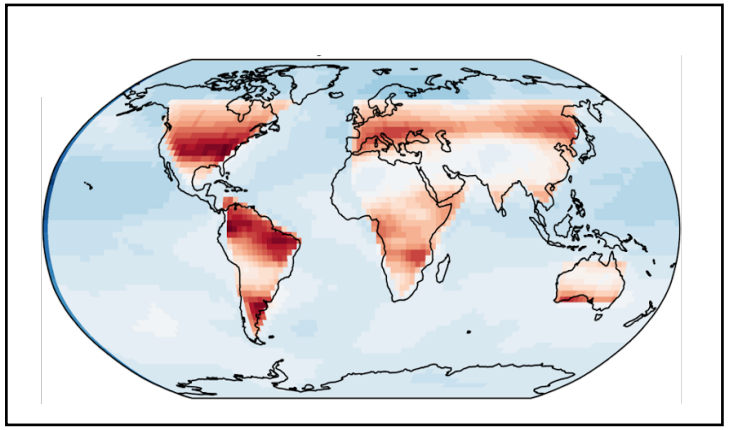
How important is this mechanism in the real world? Need to know (i) how much Δ water vapour is changing LW↓ (ii) what clouds do

Without the continental ↓ in water vapour, surface temperatures would be even warmer

↓ Surface Latent Heat Flux (warms)

↓ Water vapour over continents (cools)

Land warms from suppressing terrestrial evaporation (Isca)



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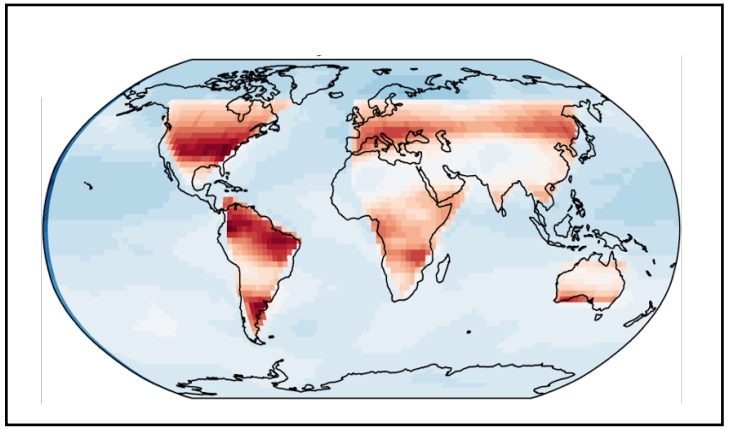

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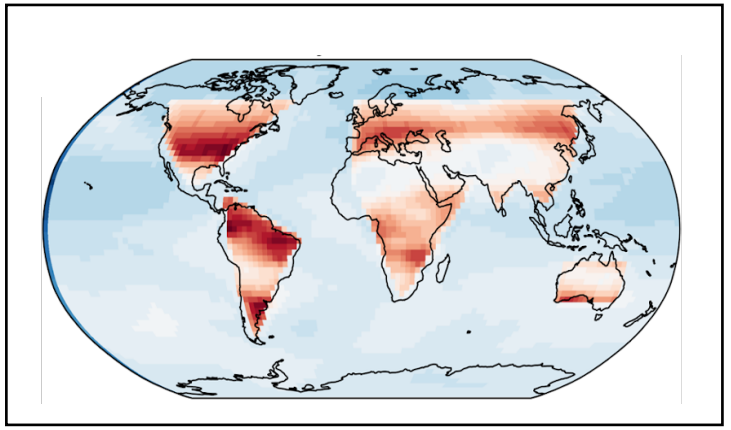

Surface Latent Heat Flux (warms)

Water vapour over continents (cools)

Both these processes impact clouds

And clouds impact surface temperatures

Use an atmospheric radiative kernel to determine how much ΔLW↓ at the surface comes from Δ water vapour

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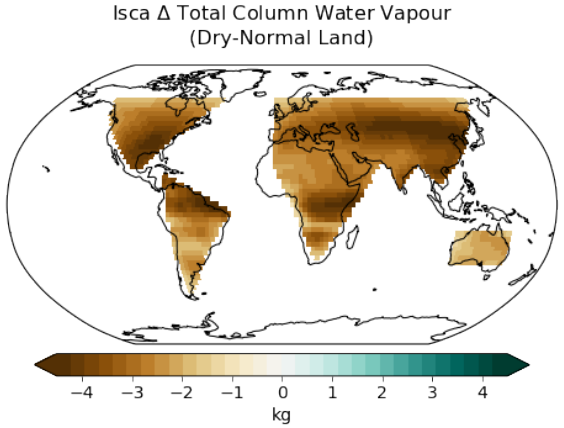
Cloud-free model (Isca):

Air gets drier



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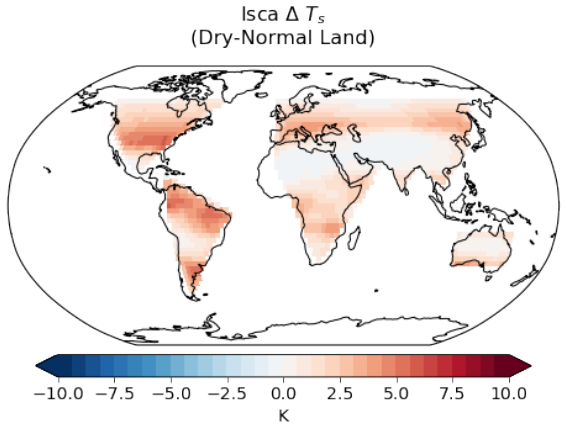

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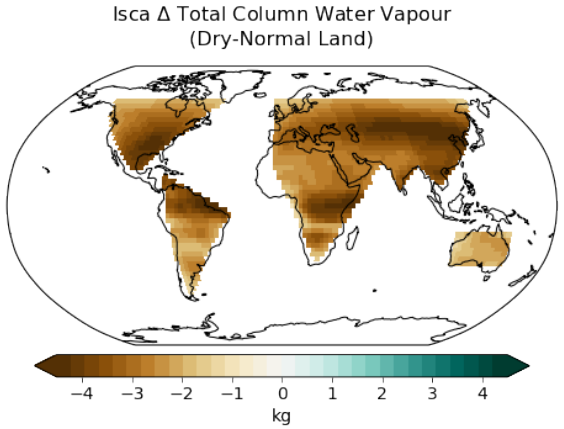

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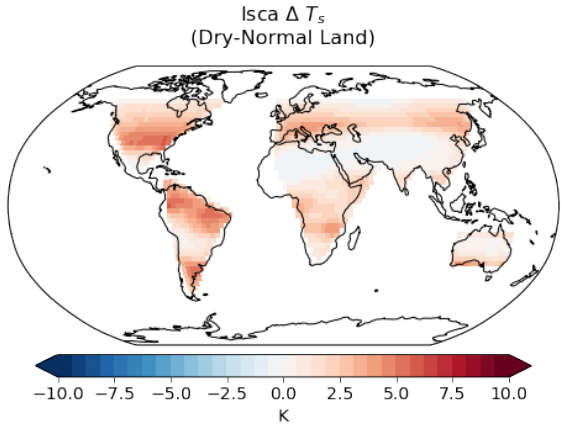
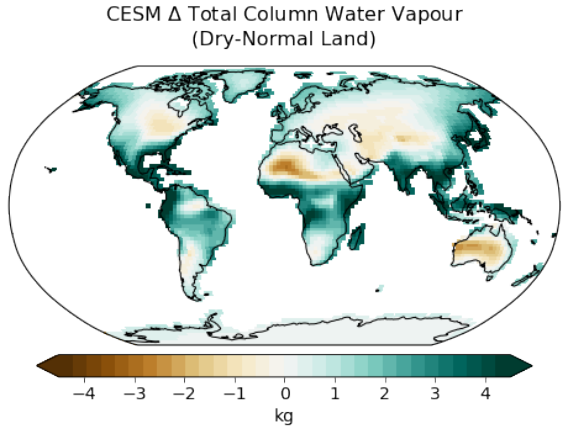


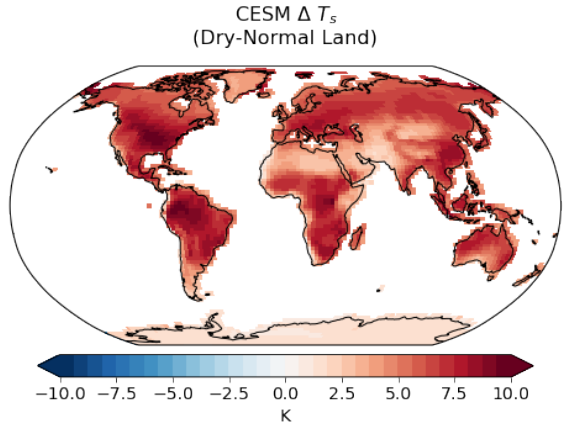
Model with clouds (CESM):

Air only gets drier some places

(warmer air can hold more water)



Land gets a lot warmer (cloud response helps warm, here)



Warmer air can *hold* more water, and total Δ water vapour from ↓ land evaporation depends on cloud cover! (Not as tidy a story as in the idealized model!)

Cloud-free model (Isca):

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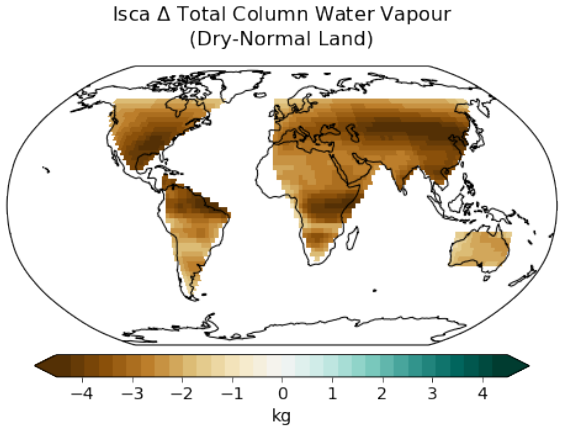

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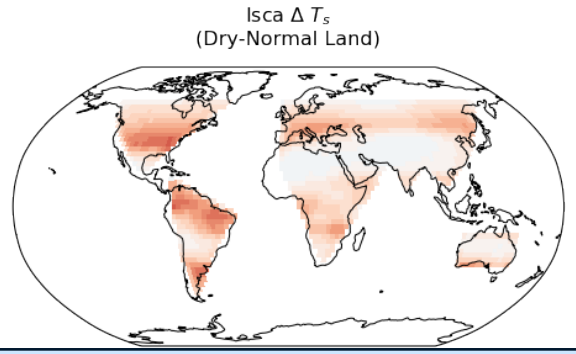

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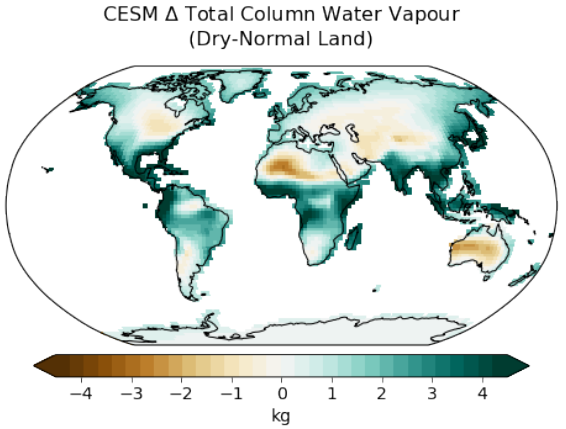

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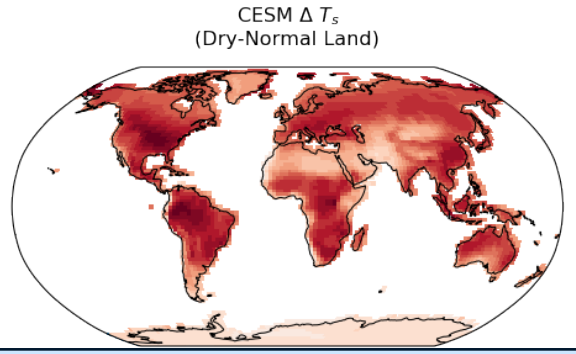

Even *with* cloud feedbacks, would still expect giant continents (like Northland) to dry out the atmosphere

In Summary…

Temperature response to ↓ land evaporation is a competition between:

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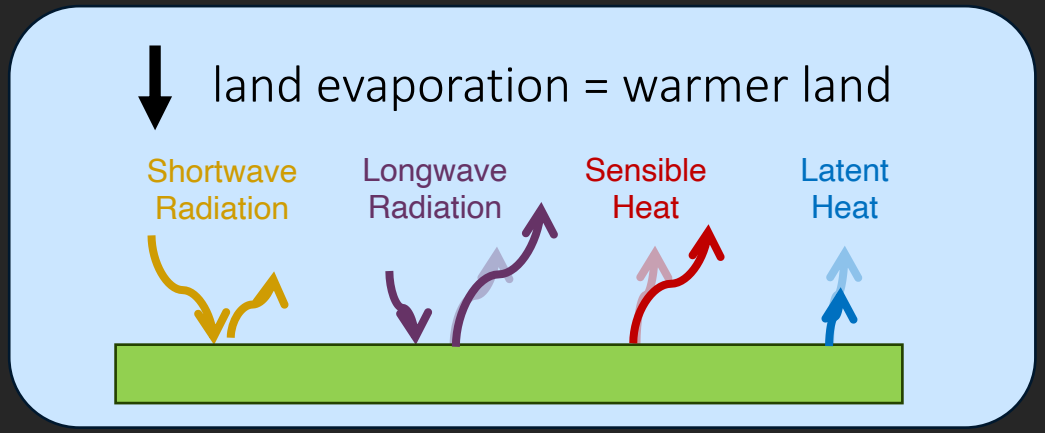
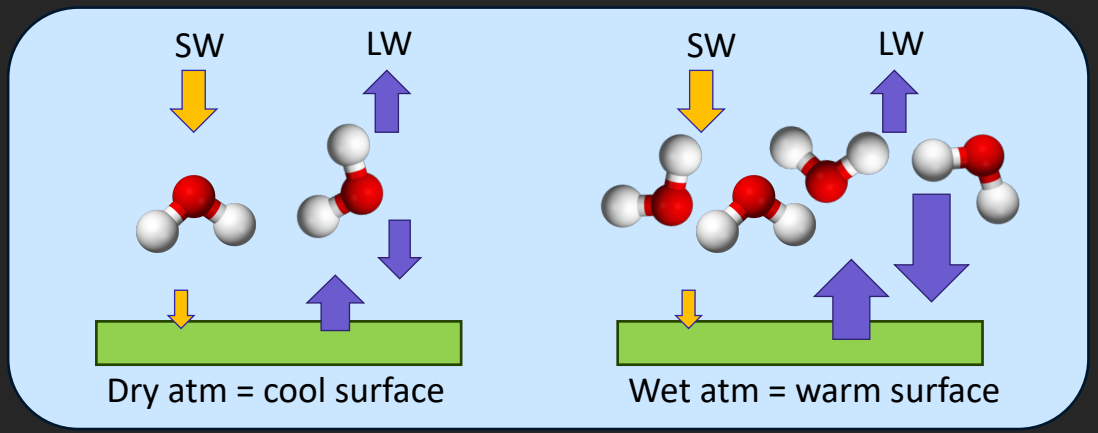


Large-scale cooling (greenhouse effect)



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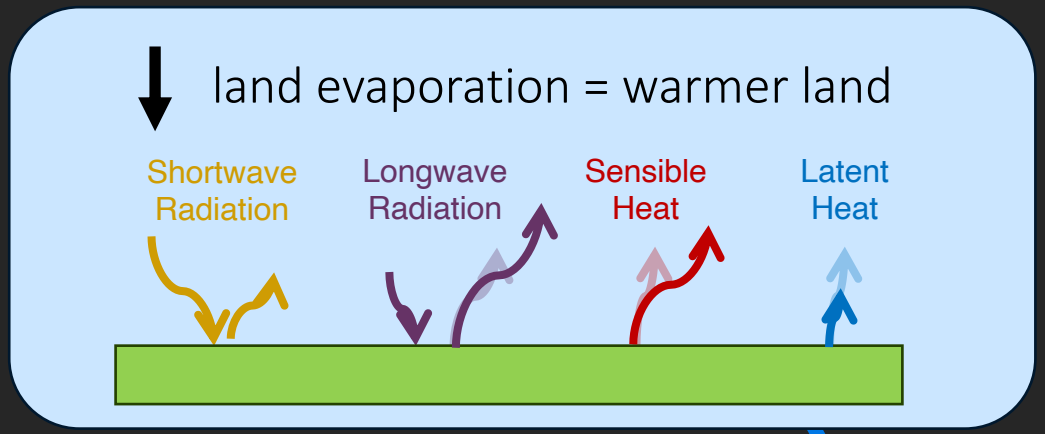

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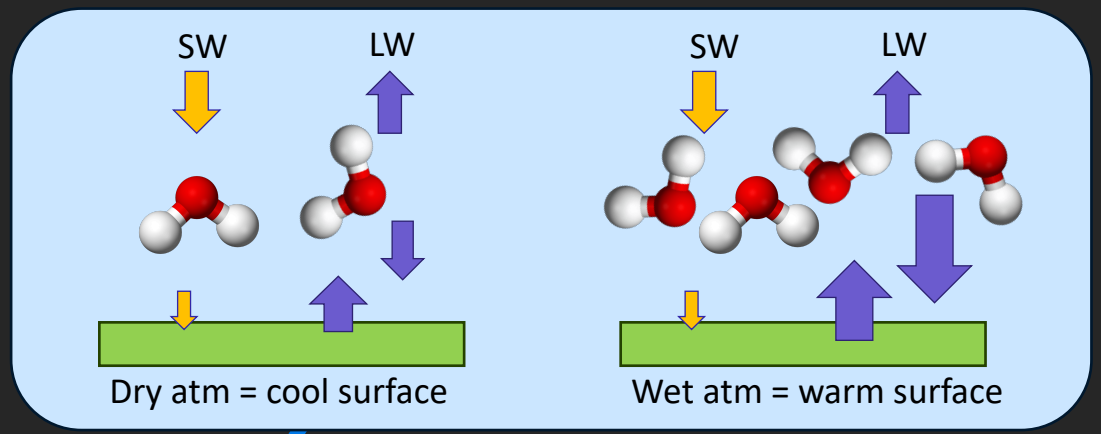

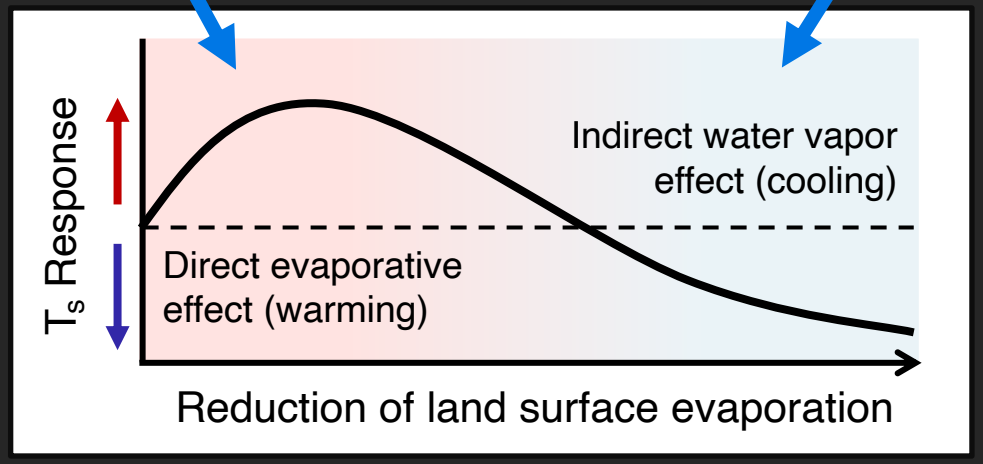

Where you sit on this curve depends on continental configuration, degree of change in evaporation, clouds, etc…

marysa.lague@usask.ca