

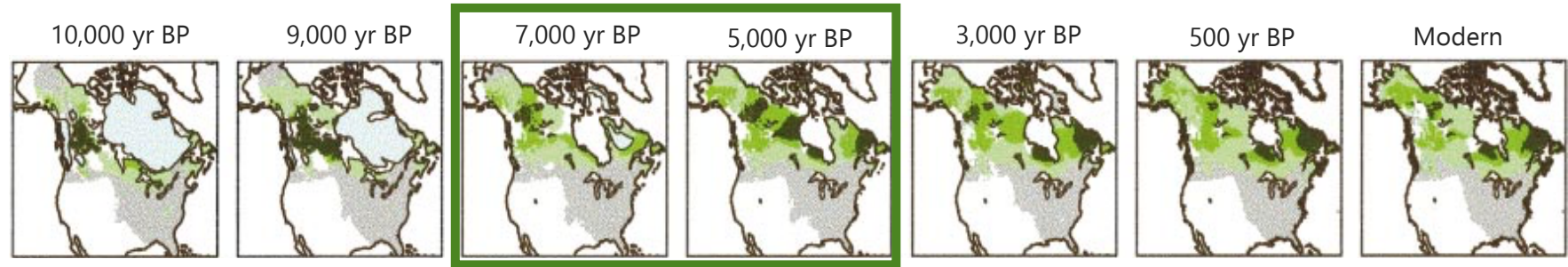
Beautiful Days in the Neighborhood:
Modeling Self-Perpetuated Climate and Forest Expansion during
the Mid-Holocene

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Abigail Swann (UW), Marysa Laguë (USask, UC Berkeley)



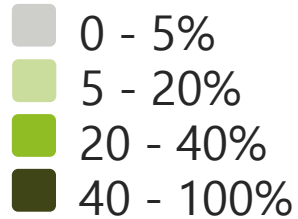
Post-glacial boreal forest establishment and expansion took place during the mid-Holocene.



Williams, J. W., *et al.* Late Quaternary Vegetation Dynamics in North America: Scaling from Taxa to Biomes. *Ecological Monographs* 74(2), 309-334 (2004).

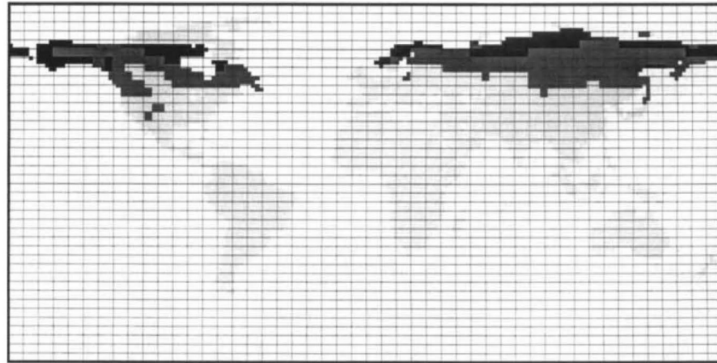


Picea (Spruce)

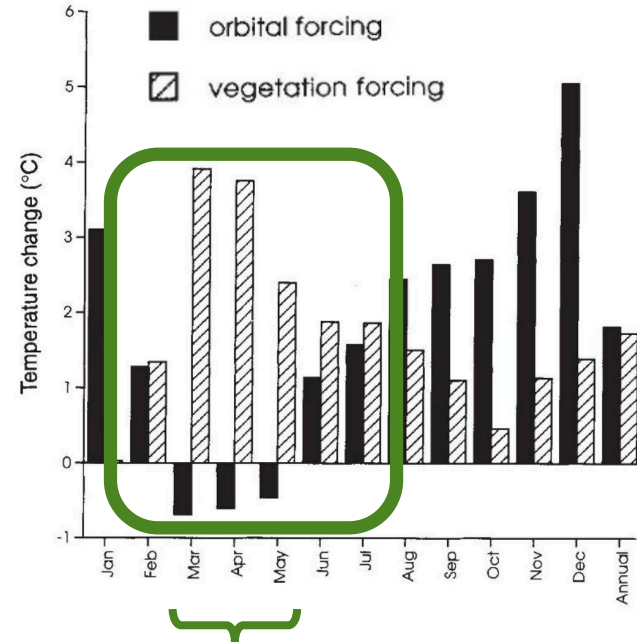


Prior work shows that forest expansion at high latitudes in general and specifically in the mid-Holocene can influence climate.

■ modern forest
■ imposed forest expansion



Foley, J., Kutzbach, J., Coe, M. *et al.* Feedbacks between climate and boreal forests during the Holocene epoch. *Nature* 371, 52–54 (1994).



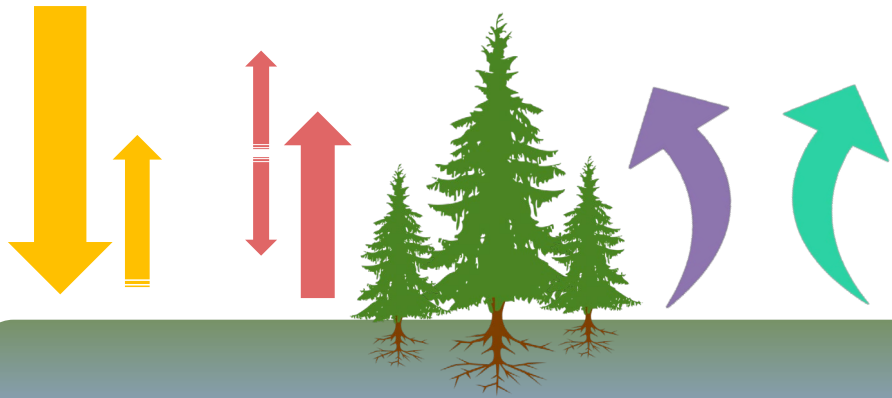
Found springtime warming *just* due to trees!

Could land-atmosphere interactions influence the climate enough to drive forest expansion?

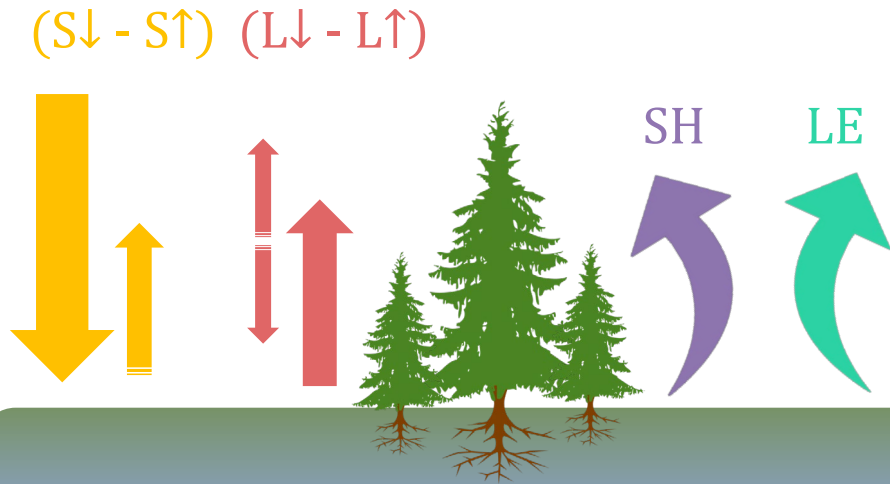
Could land-atmosphere interactions influence the climate enough to drive forest expansion?



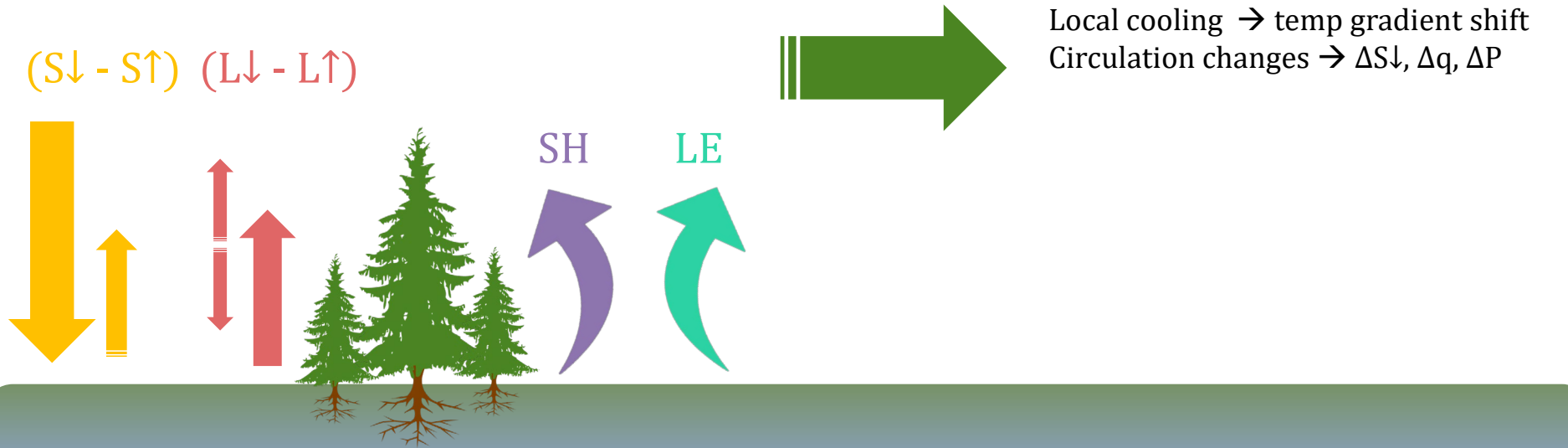
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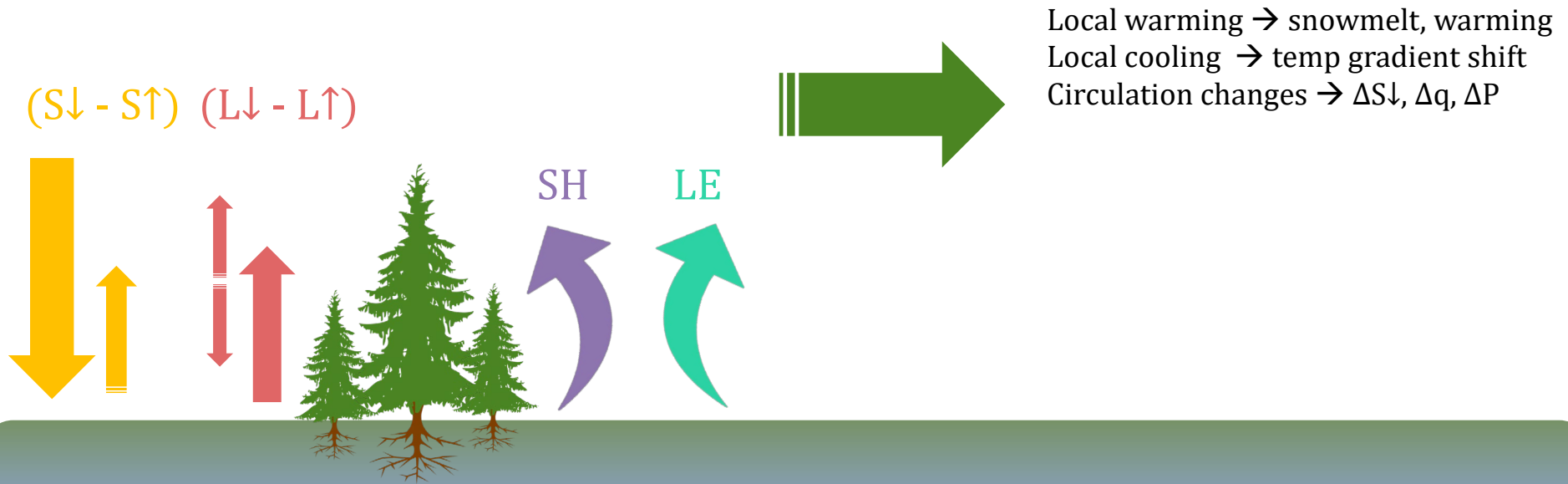
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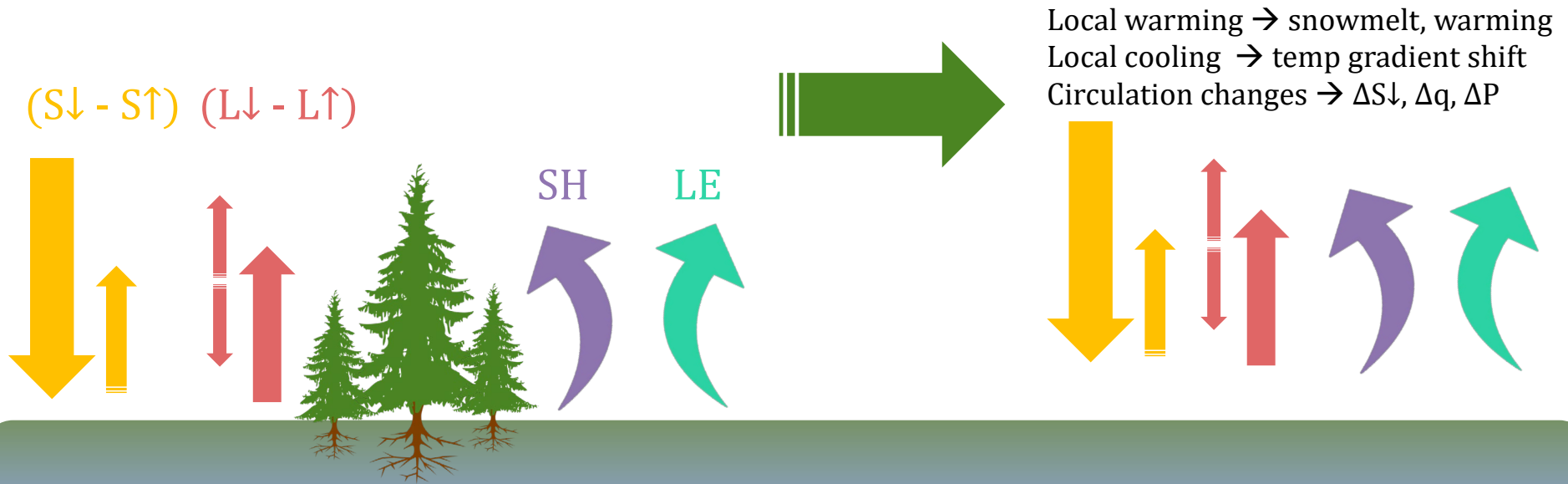
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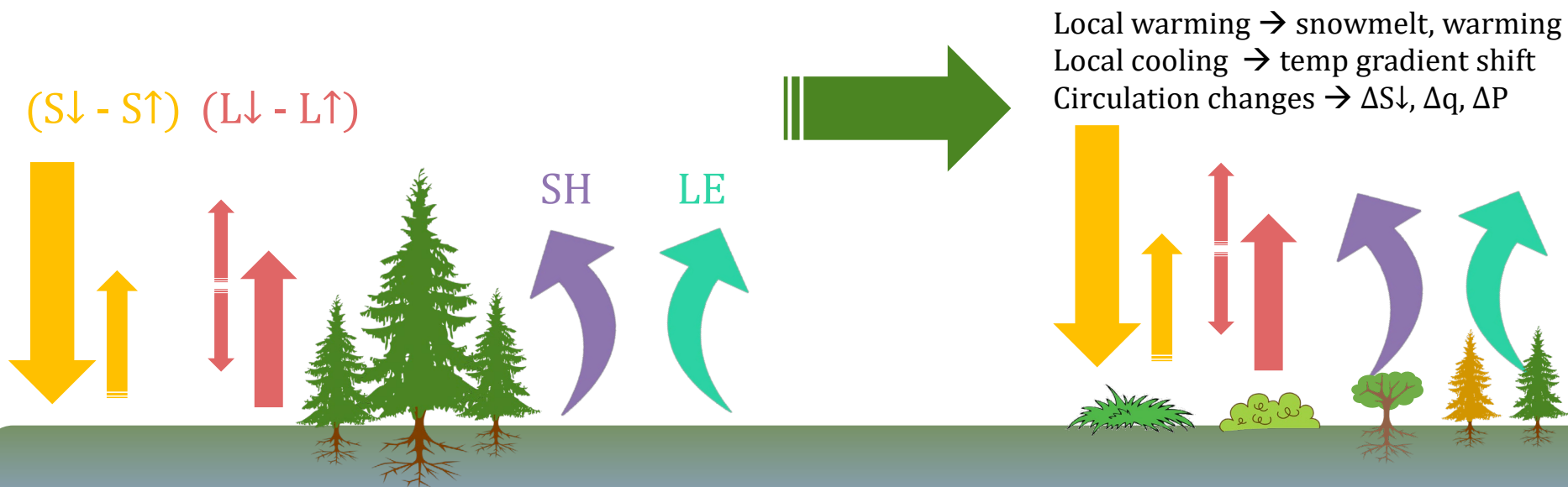
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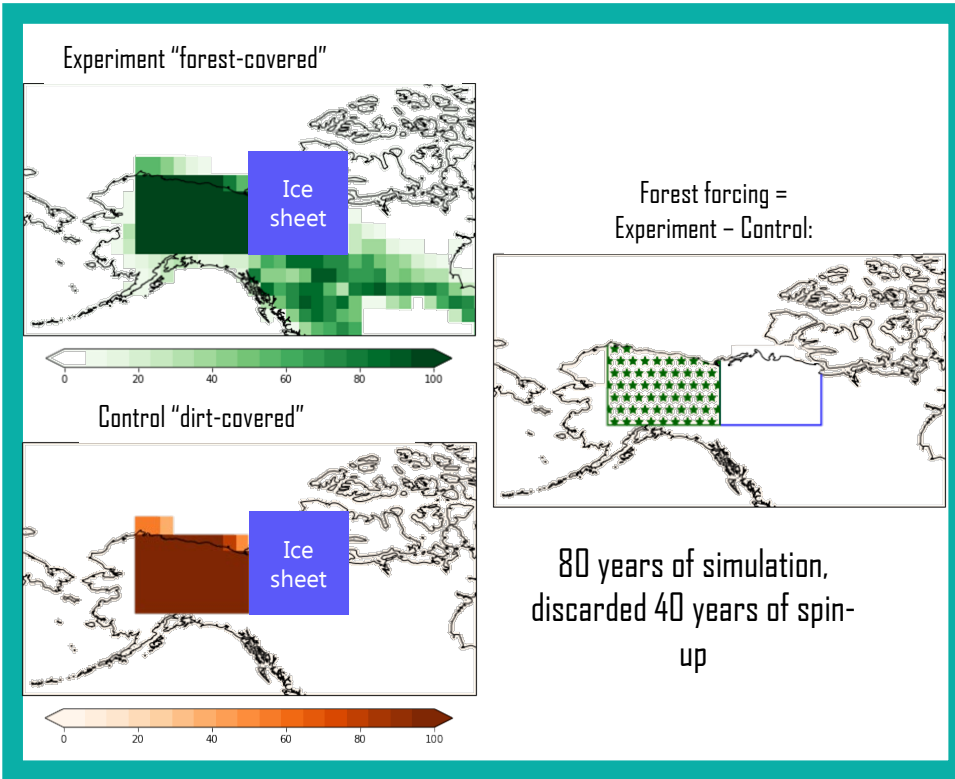


Could land-atmosphere interactions influence the climate enough to drive forest expansion?



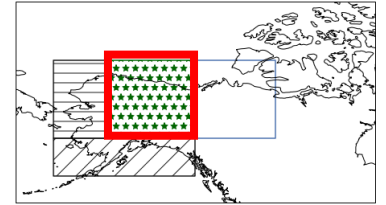
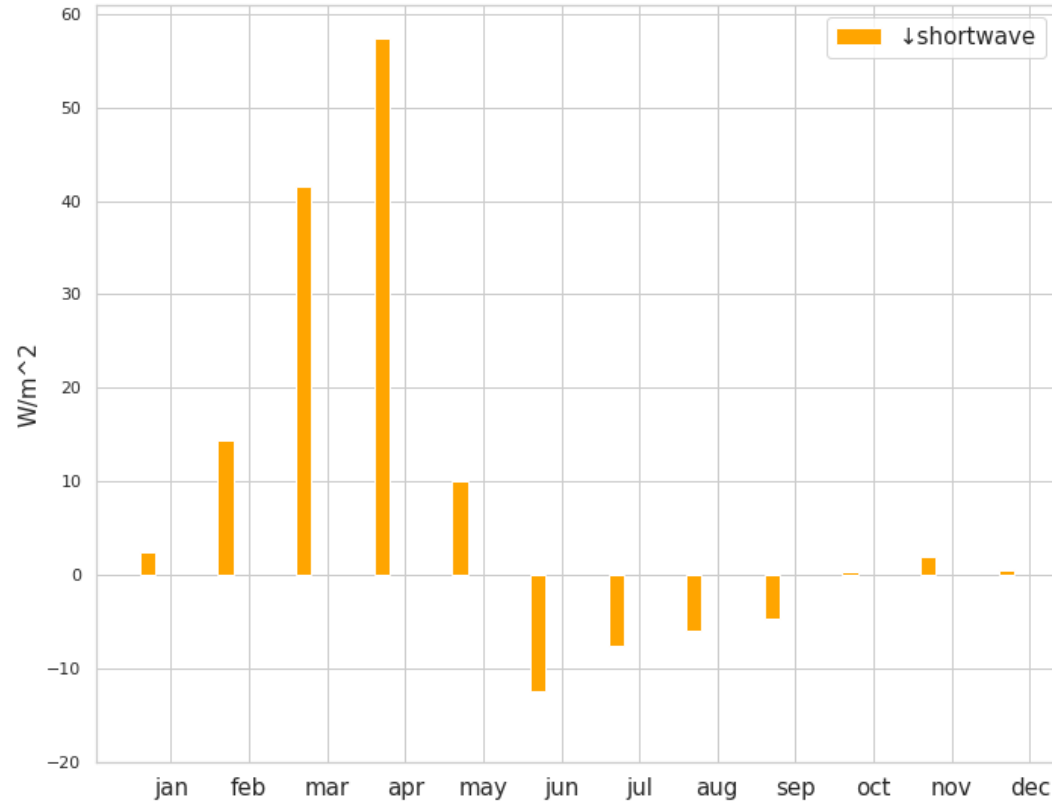
Simulated forest emergence adjacent to glacier land units (flattened) to isolate the climate changes

Phase 1: Coupled CAM6, CLM5 2 degree, 6000 BP

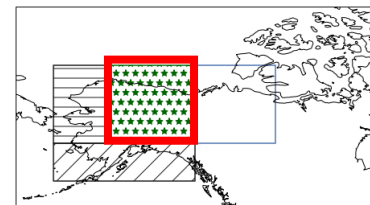
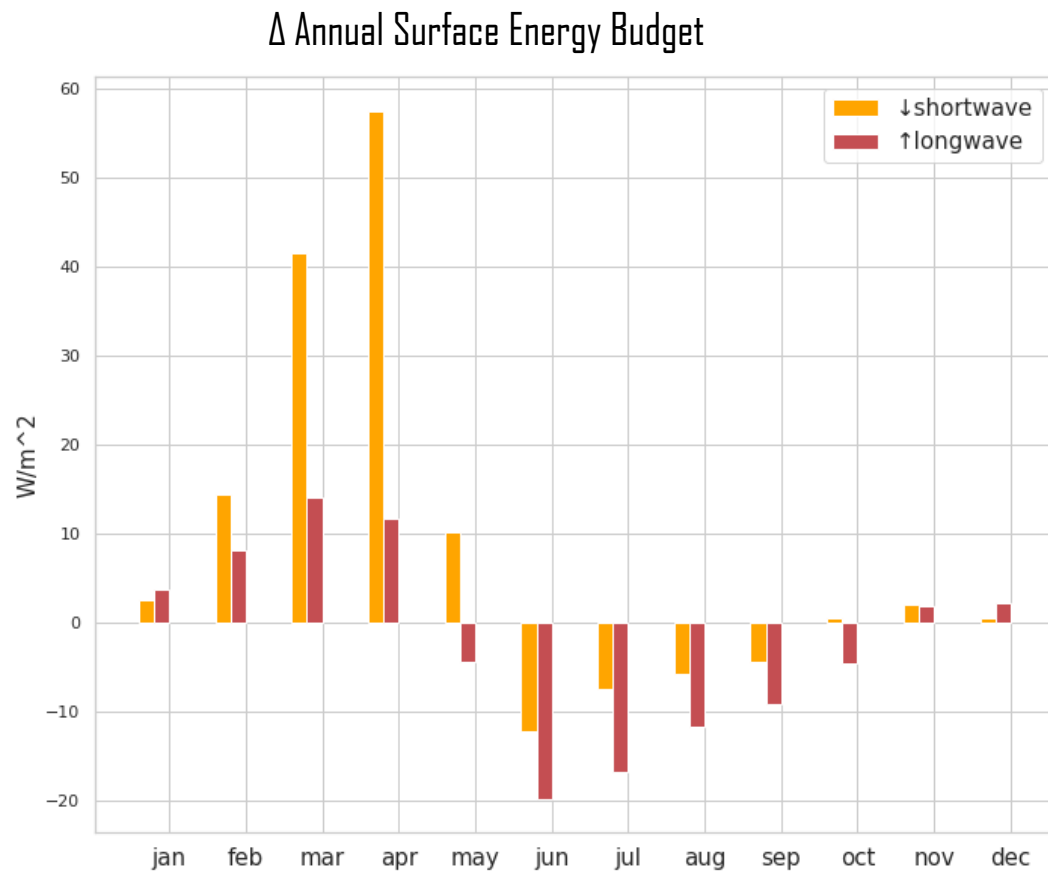


Inside the box: Spring gets summer while summer gets cloudier

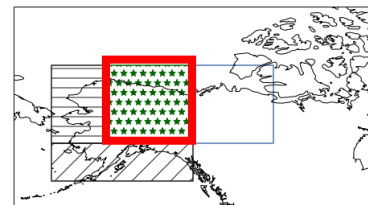
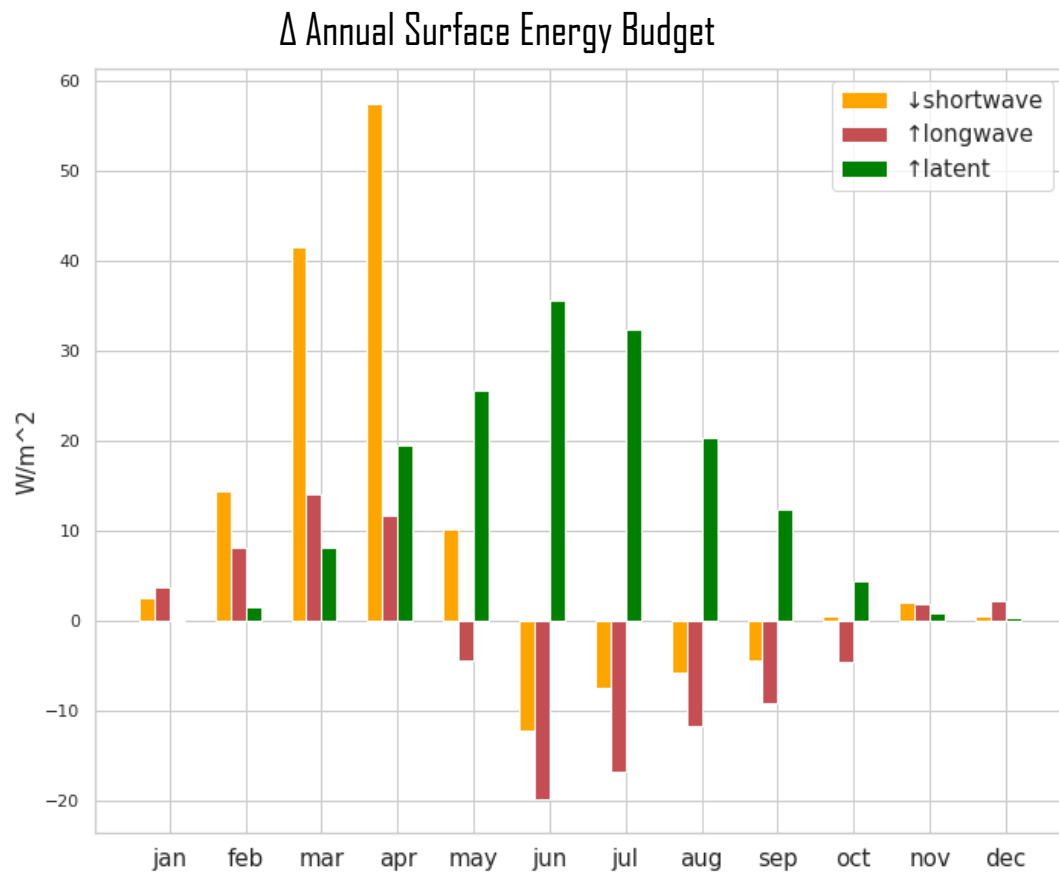
Δ Annual Surface Energy Budget



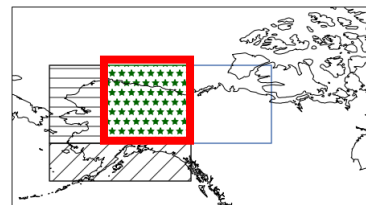
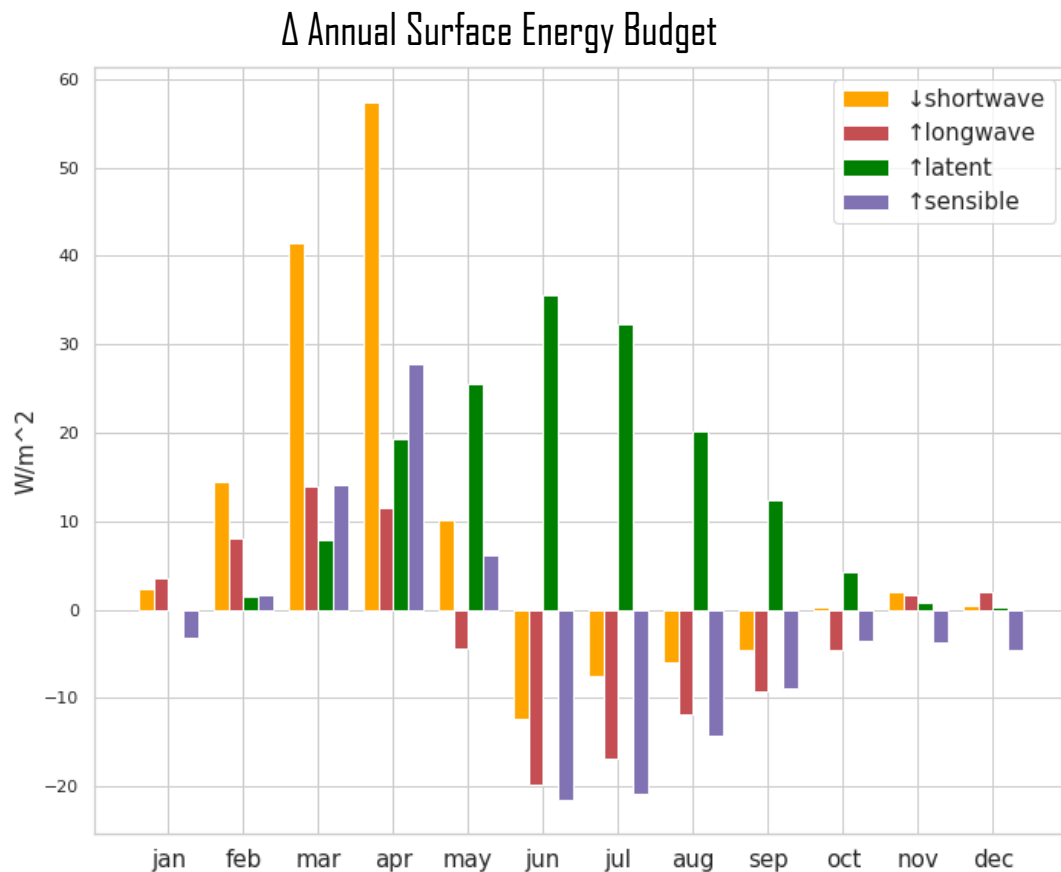
Inside the box: Longwave shows springtime warming and summertime cooling.



Inside the box: More latent heat flux during the growing season because plants are transpiring more

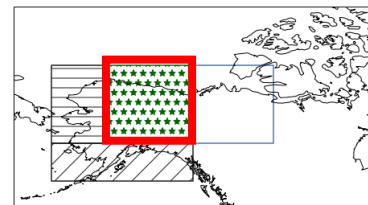
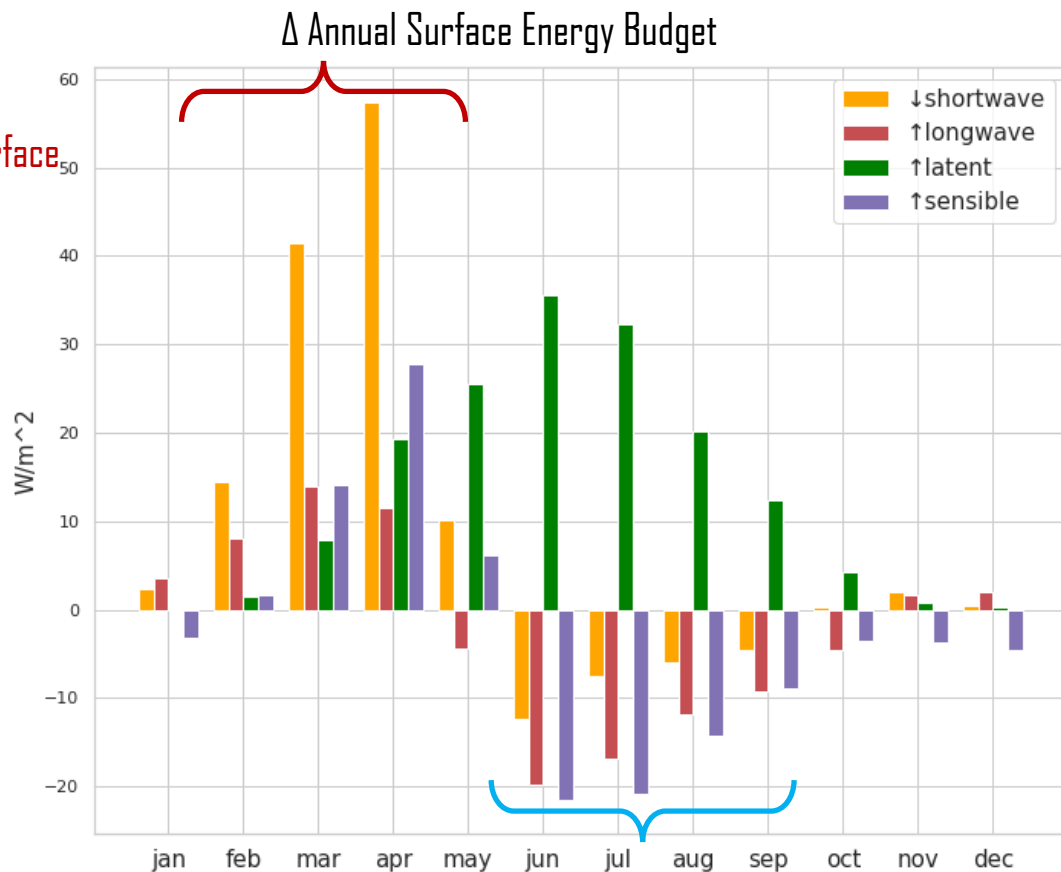


Inside the box: Sensible heat flux follows changes in surface temperature.



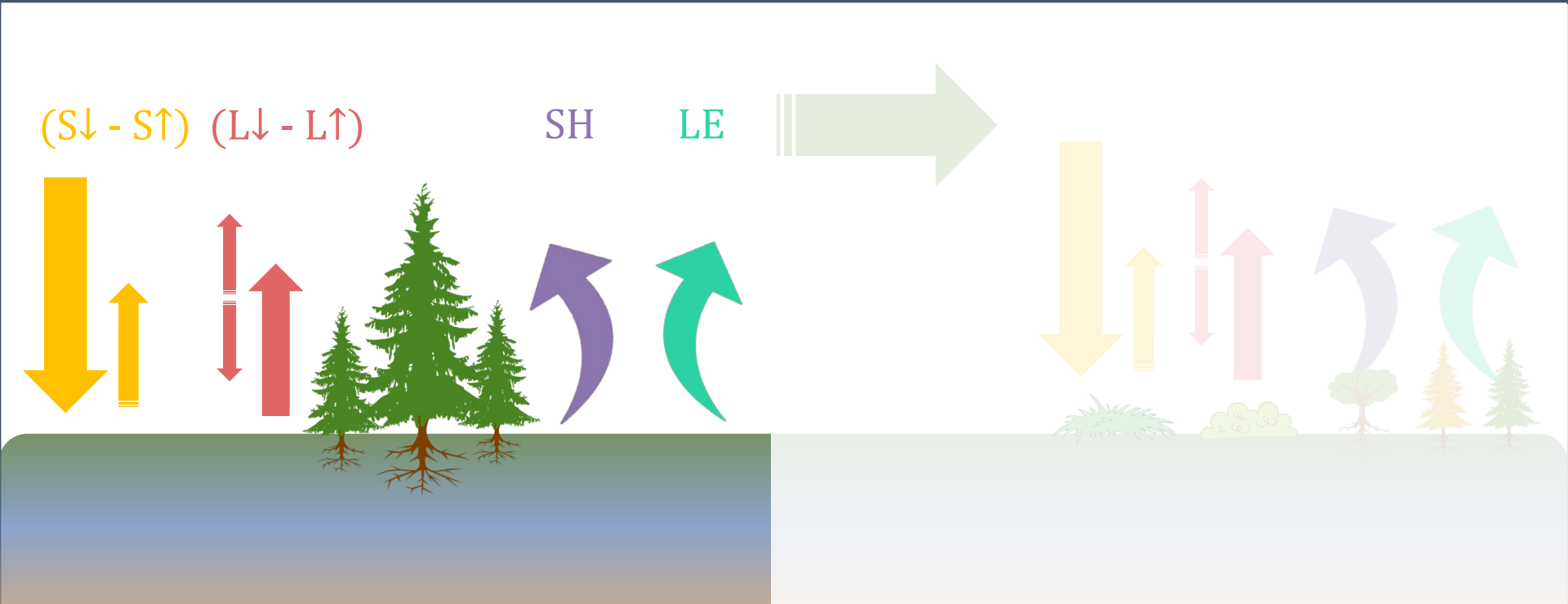
Warming and cooling matches Foley et al. 1994

Warming in spring,
stronger impact of surface
albedo

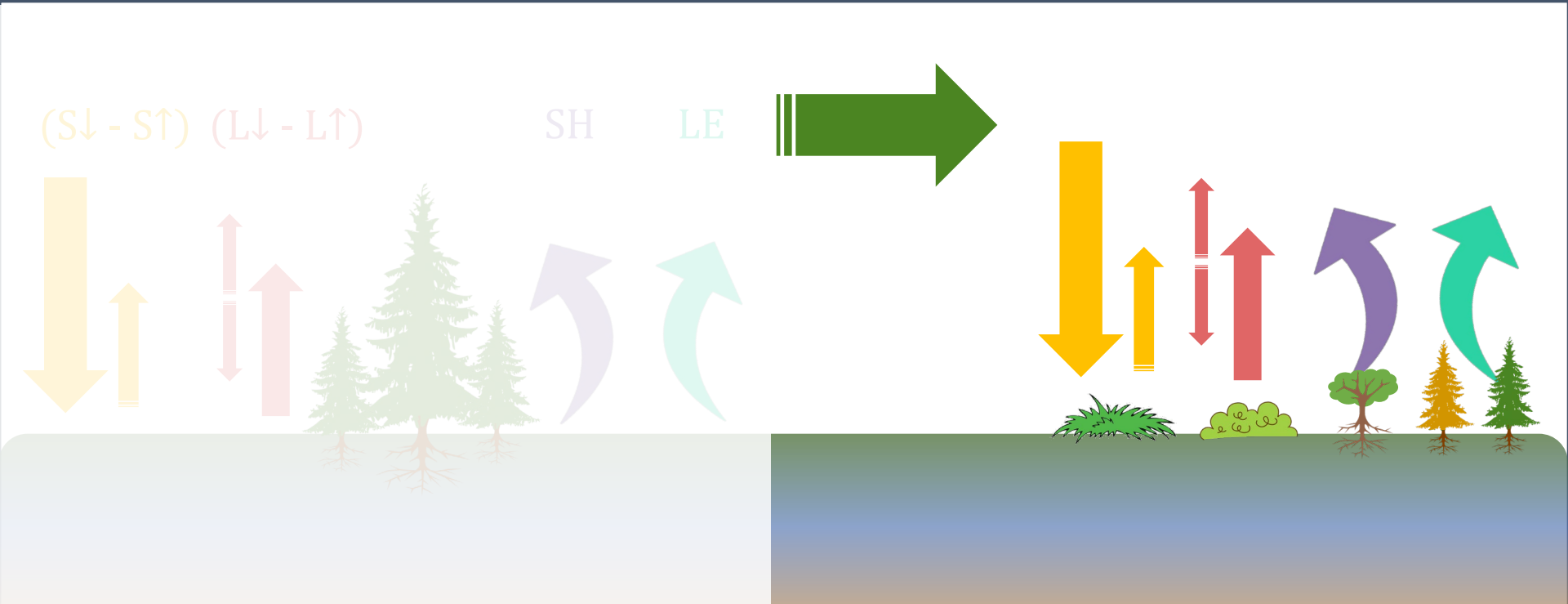


Cooling in summer, stronger
impact of cloud changes

That's what happens over the forest.

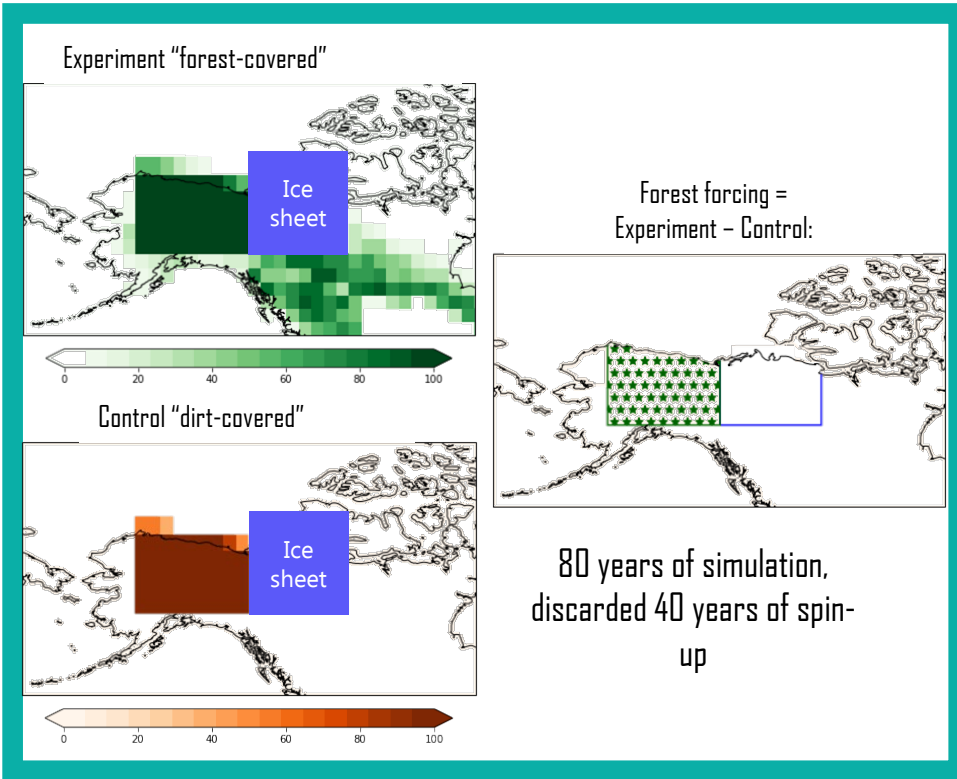


What are the regional consequences?

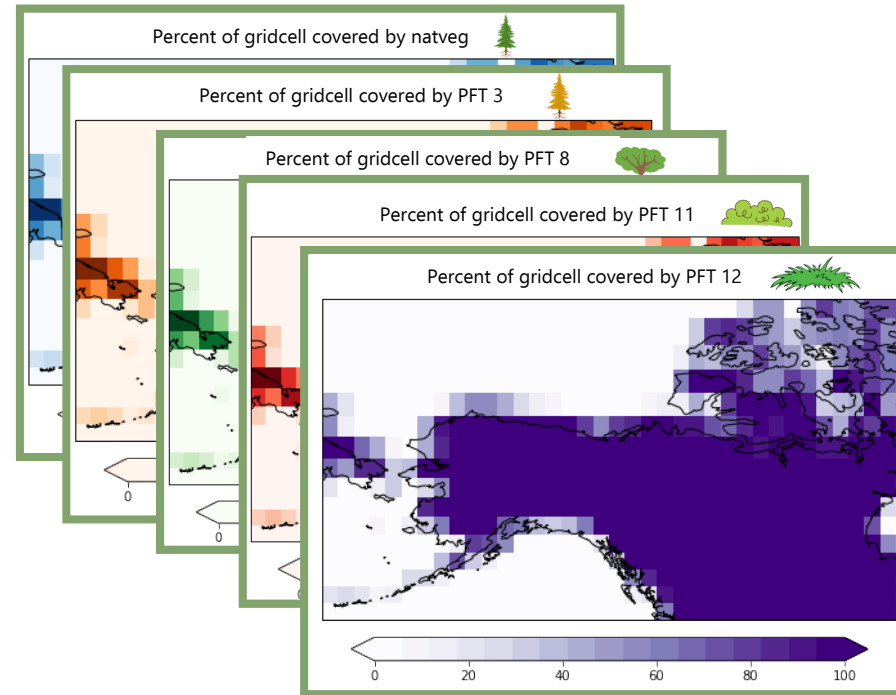


Land-only CLM runs using saved atmospheric were used to determine impact on forest expansion.

Phase 1: Coupled CAM6, CLM5 2 degree, 6000 BP



Phase 2: assess GPP changes in land-only CLM5 simulation driven by Phase I atmospheric state



Plants grew better (across all PFTs) to the west and south of the area where we imposed a forest.

needleleaf evergreen boreal tree



needleleaf deciduous boreal tree



broadleaf deciduous boreal tree

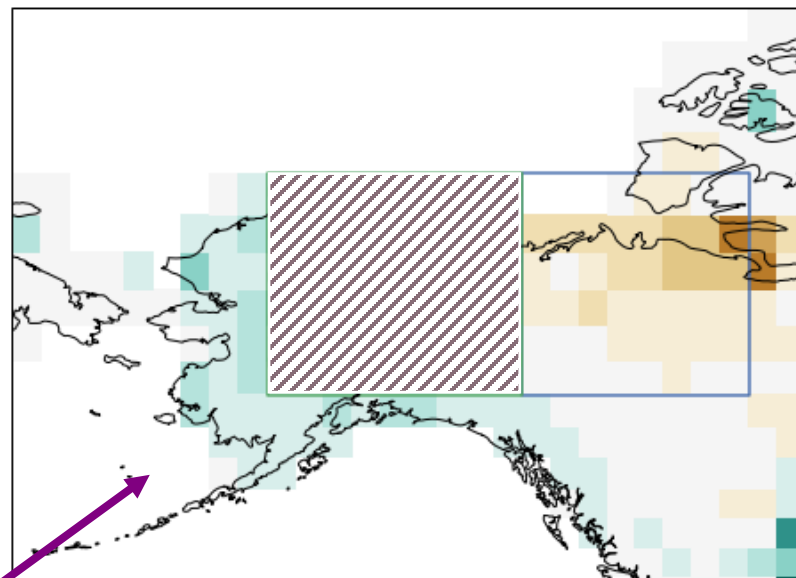


broadleaf deciduous boreal shrub

arctic C3 grass



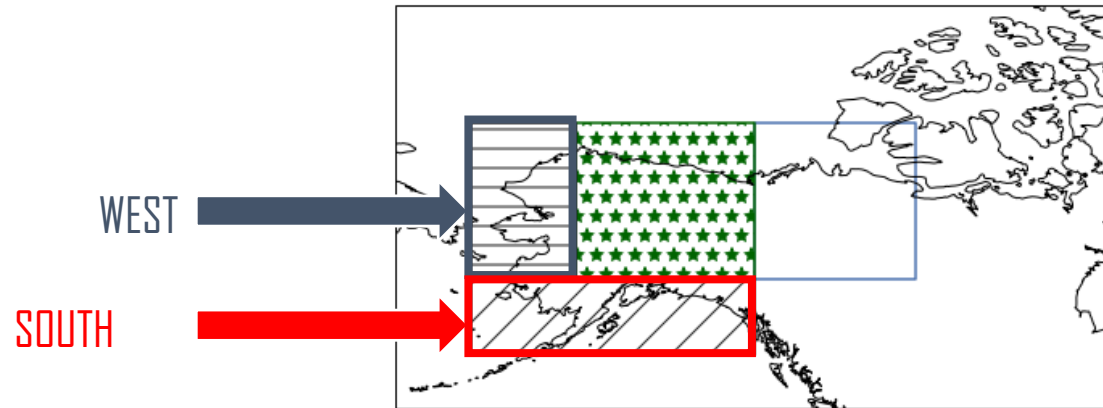
Δ Summer GPP



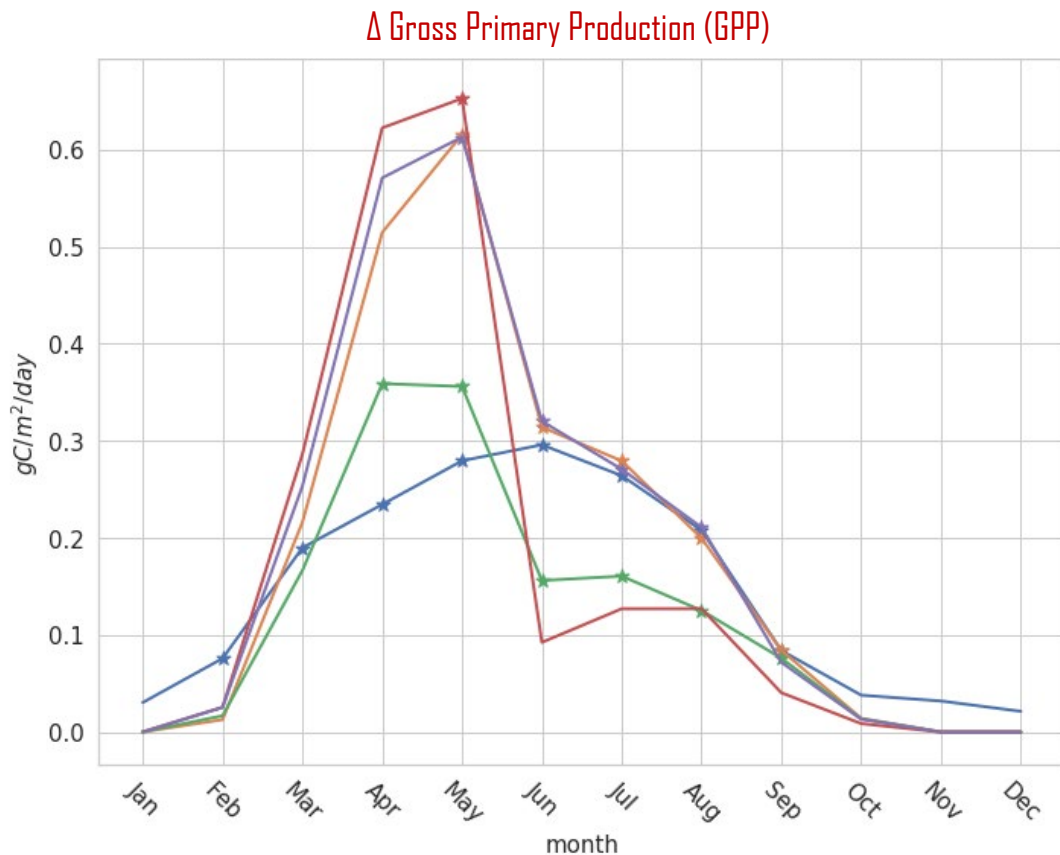
-2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0

$\text{gC}/\text{m}^2/\text{day}$

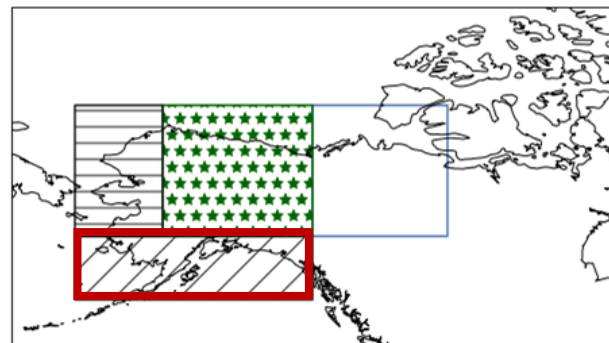
Changes in growth to the west and south are driven by independent mechanisms. (Today we will focus on the south.)



Plants increased in productivity to the south of the established forest throughout the duration of the growing season.



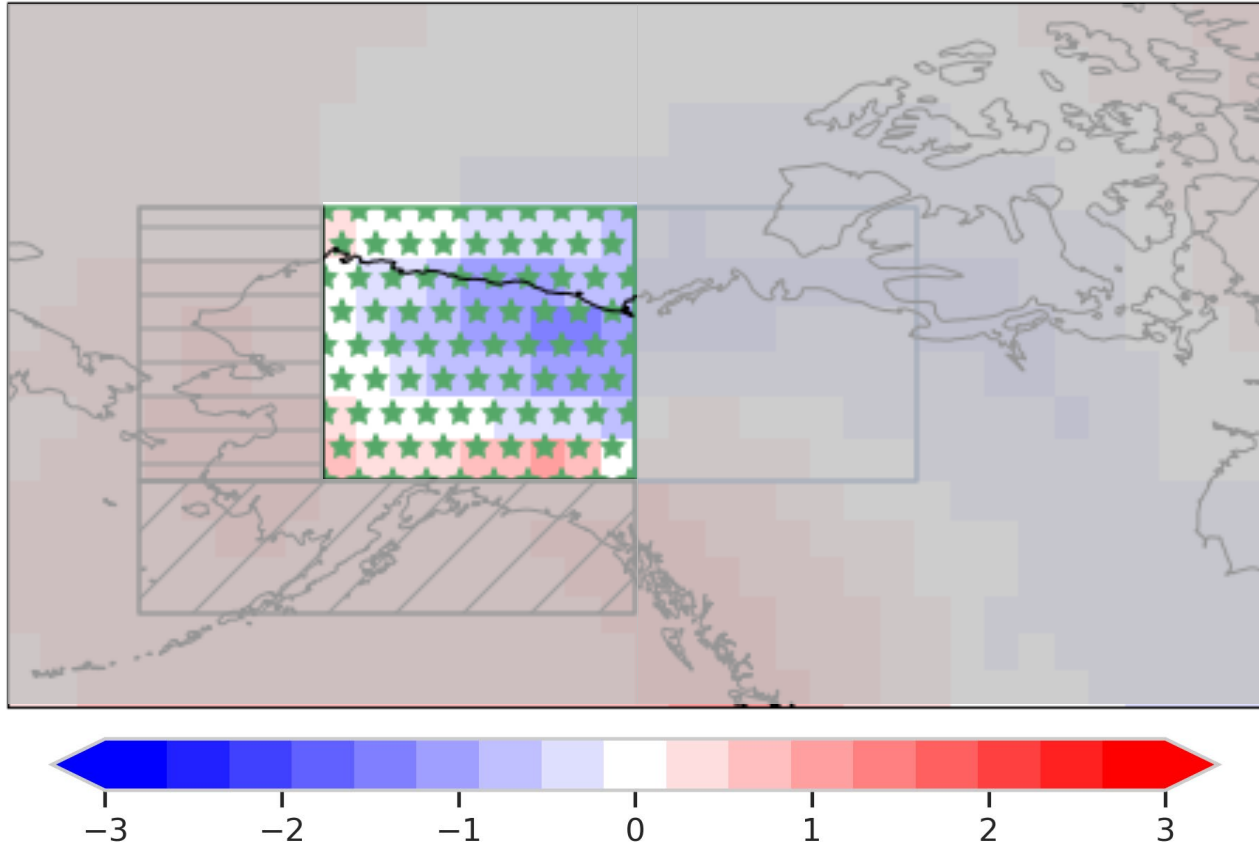
- needleleaf evergreen boreal tree
- needleleaf deciduous boreal tree
- broadleaf deciduous boreal tree
- broadleaf deciduous boreal shrub
- arctic c3 grass



How does the forest change nearby climate?

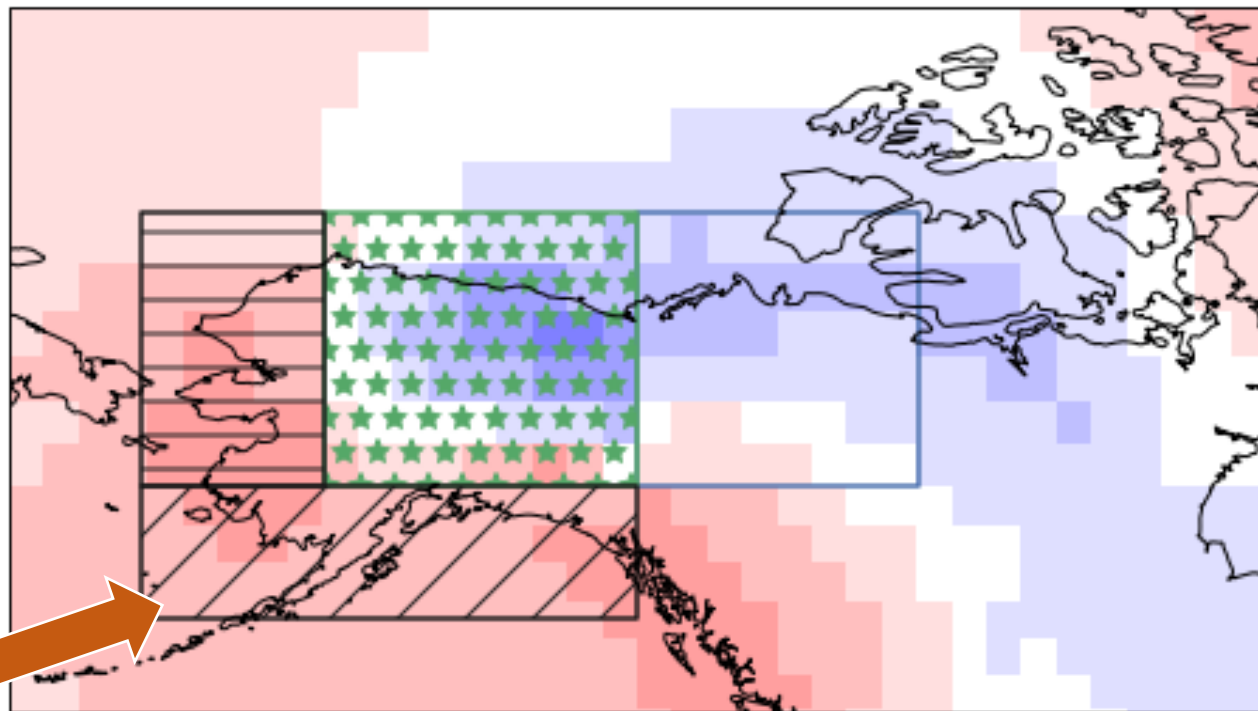
Cooling over the forest driven by clouds

Δ Summer Temperature



But warming outside the forest?!

Δ Summer Temperature

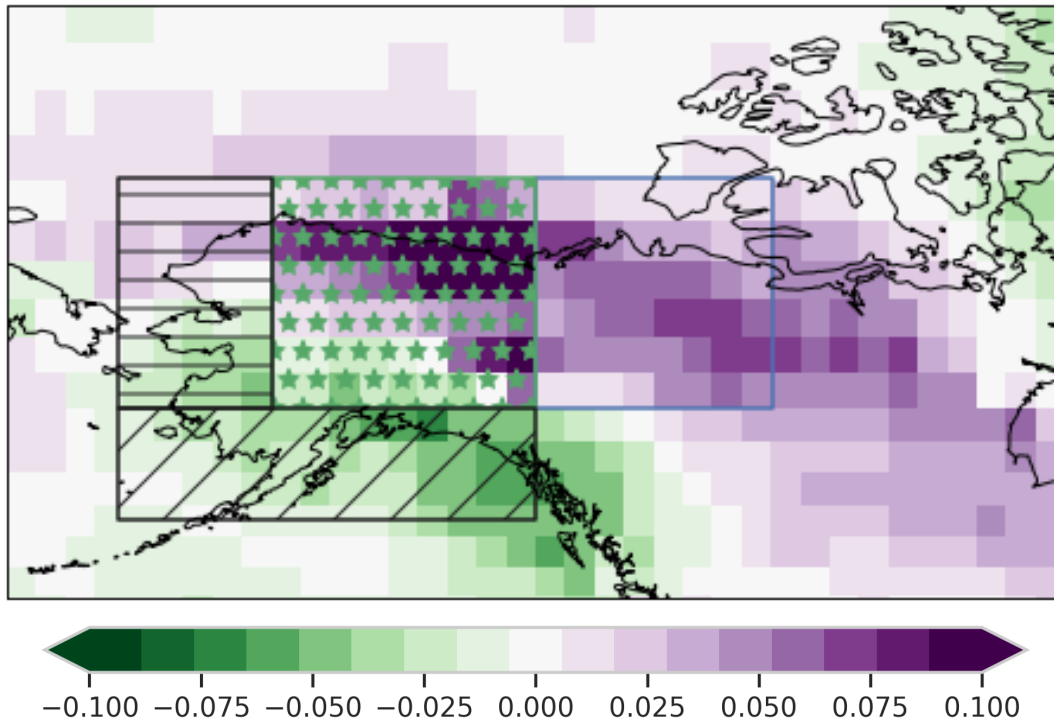


WHY?



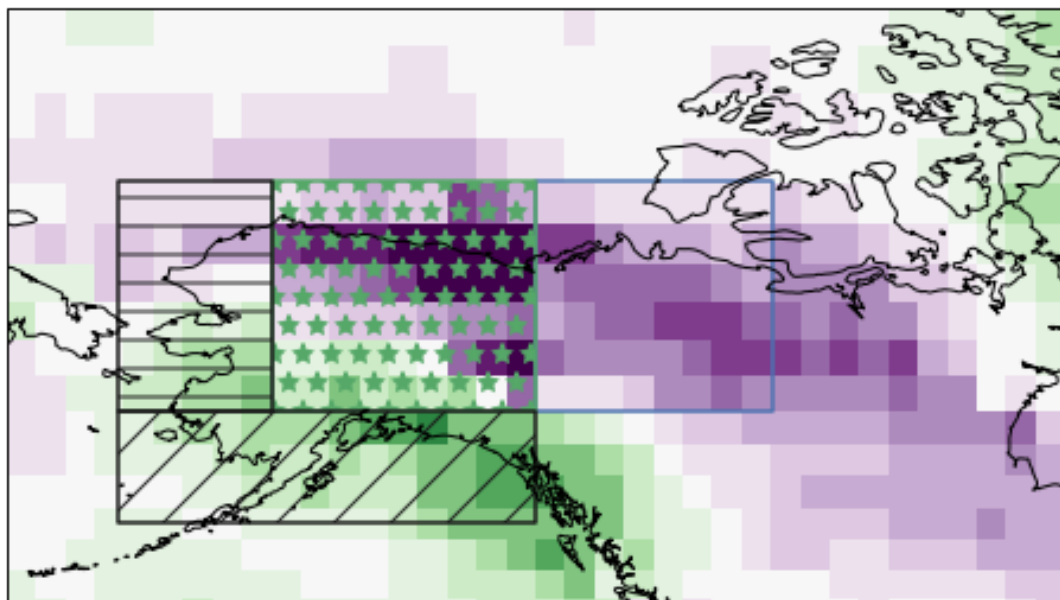
Forest drives clouds at home, but fewer clouds for its neighbors. How?

Δ Summer Low Cloud Fraction



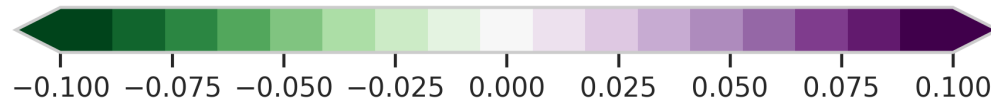
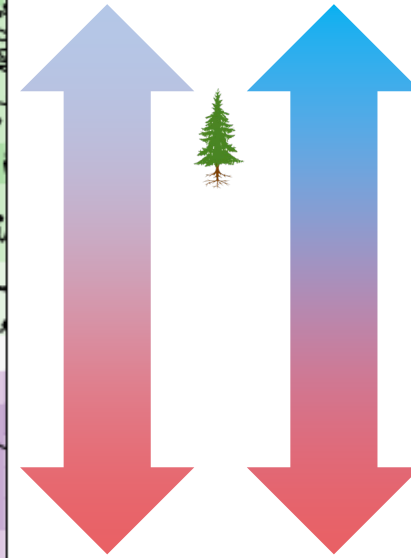
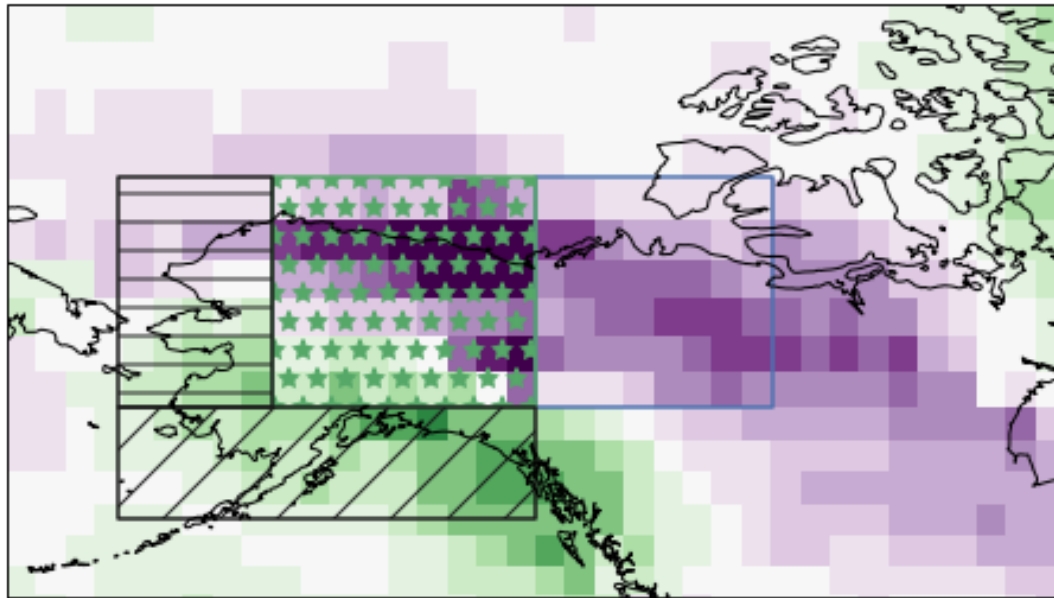
Existing meridional temperature gradient over region drives northward heat transport.

Δ Summer Low Cloud Fraction



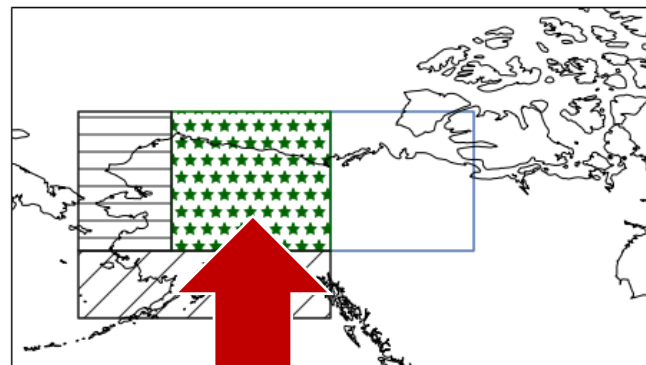
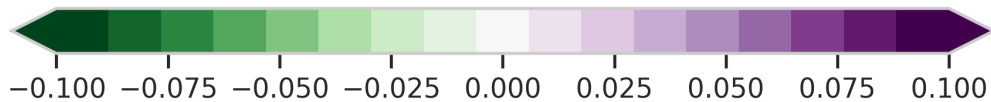
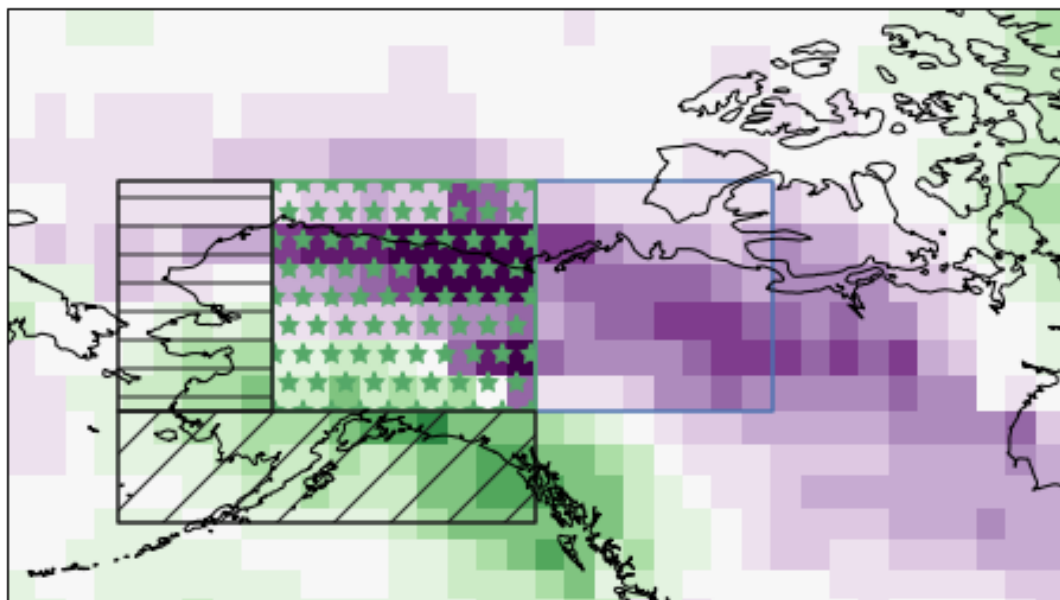
Adding a forest produces clouds that cool locally, increasing the regional temperature gradient.

Δ Summer Low Cloud Fraction



Stronger gradient drives stronger northward heat and moisture transport from Gulf of Alaska.

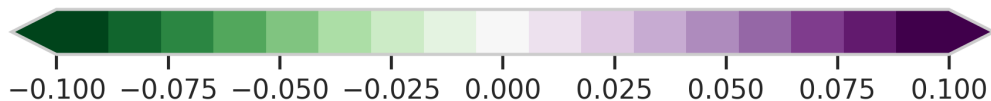
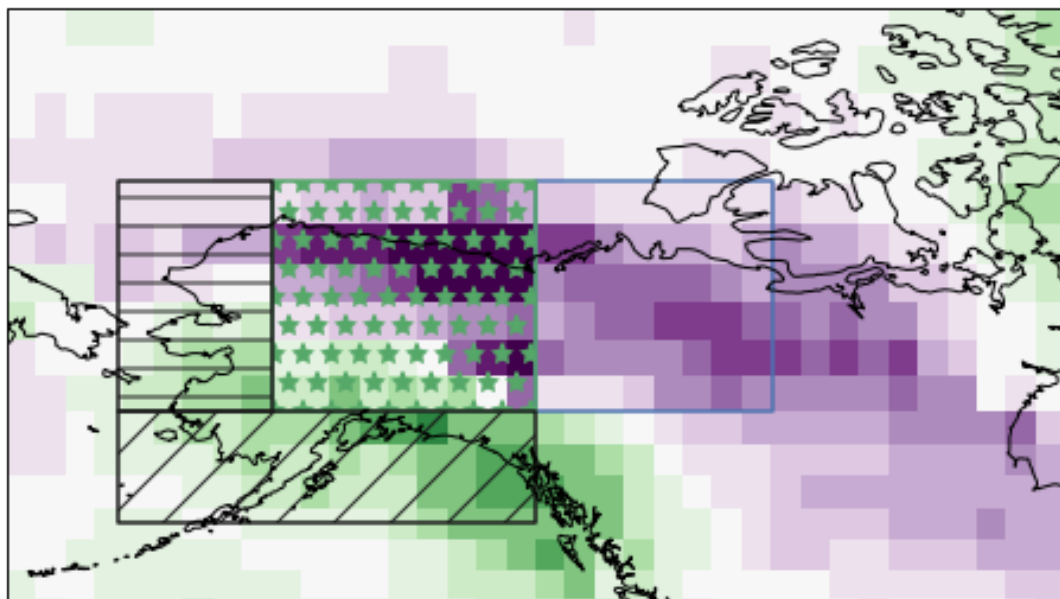
Δ Summer Low Cloud Fraction



heat &
moisture

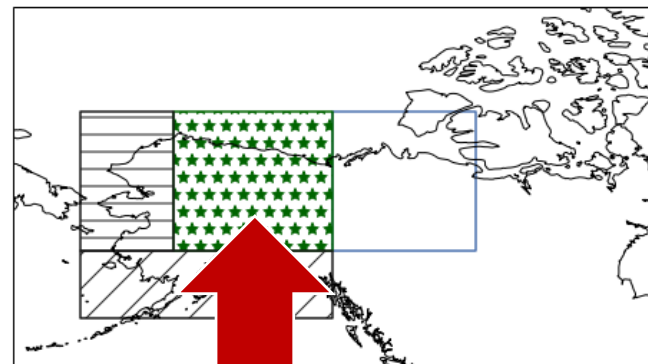
But moisture and temperature have opposing effects on relative humidity, which we can use as a proxy for cloudiness.

Δ Summer Low Cloud Fraction



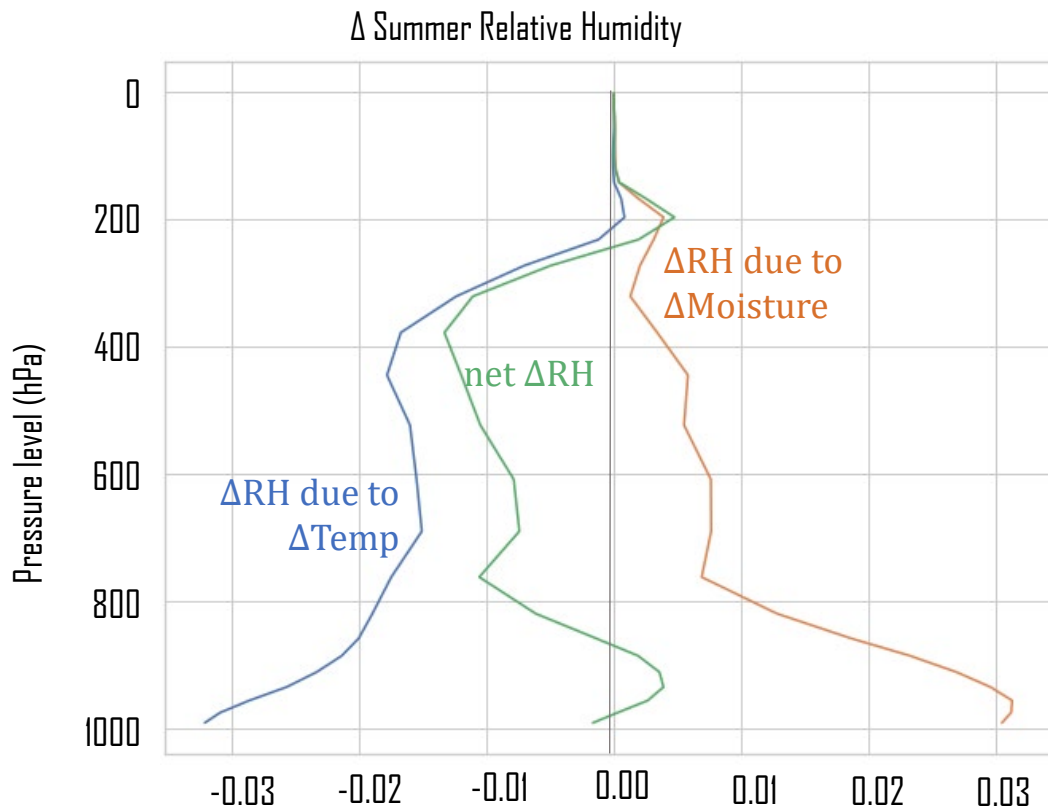
$$\Delta RH_T = \frac{q_{ctrl}}{qsat_{exp}} - \frac{q_{ctrl}}{qsat_{ctrl}}$$

$$\Delta RH_q = \frac{q_{exp}}{qsat_{ctrl}} - \frac{q_{ctrl}}{qsat_{ctrl}}$$



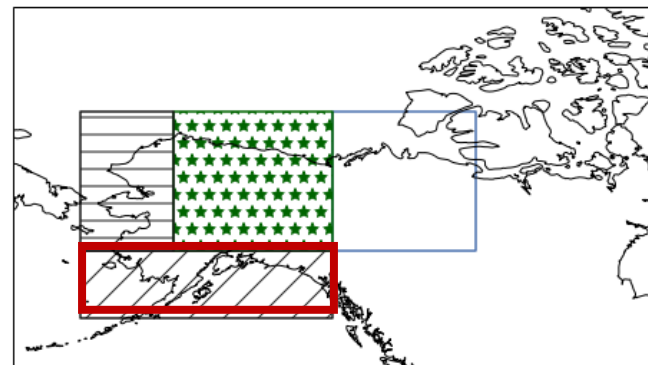
heat &
moisture

Changes in temperature, rather than moisture, determine clouds.

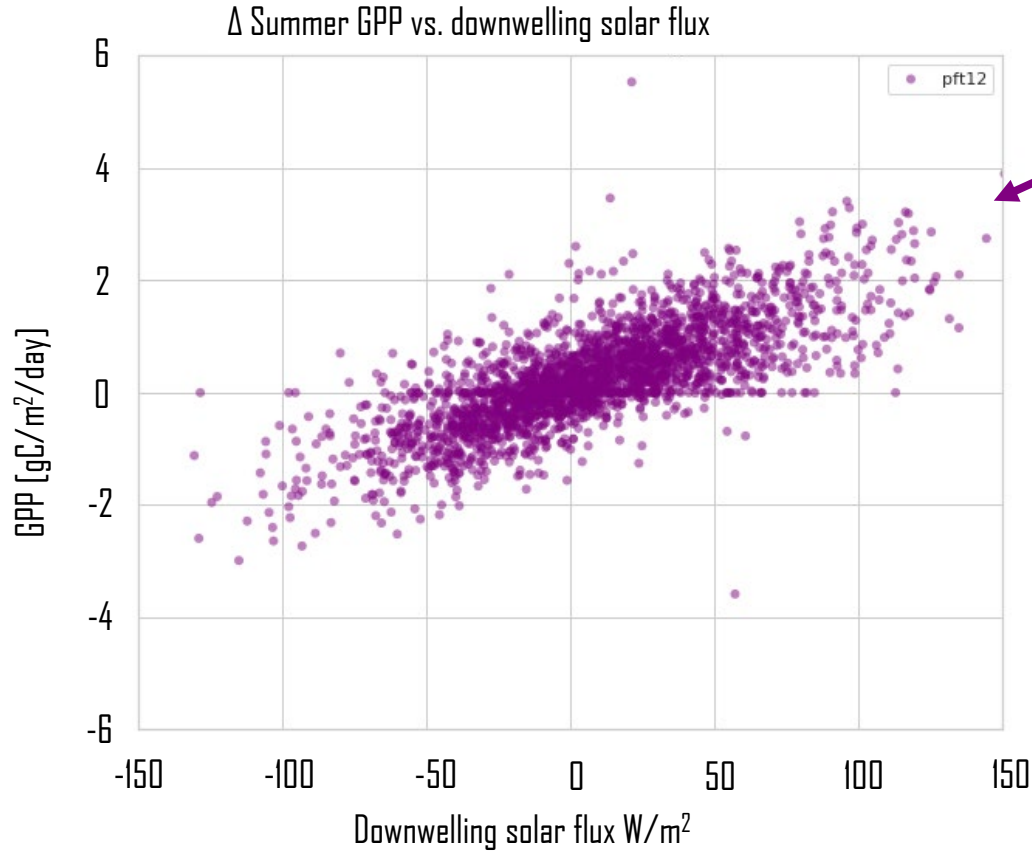


$$\Delta RH_T = \frac{q_{ctrl}}{qsat_{exp}} - \frac{q_{ctrl}}{qsat_{ctrl}}$$

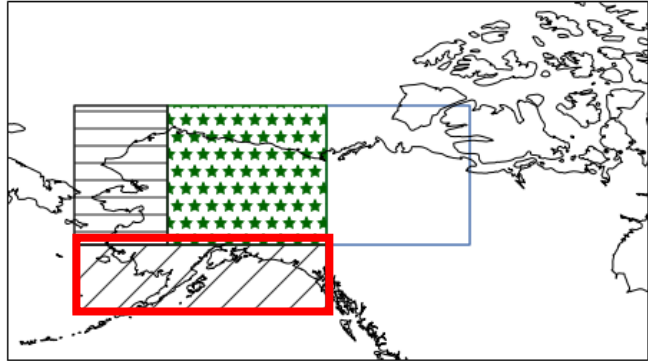
$$\Delta RH_q = \frac{q_{exp}}{qsat_{ctrl}} - \frac{q_{ctrl}}{qsat_{ctrl}}$$



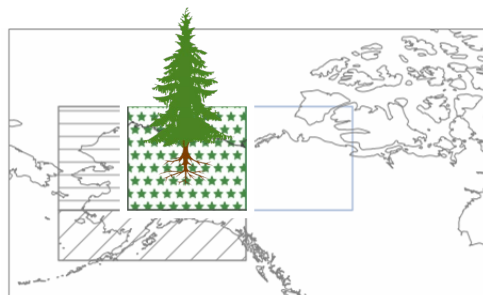
Summertime GPP responds to increase in downwelling solar flux in all PFTs. One example is arctic C3 grass.



arctic c3 grass 



The establishment of post-glacial boreal forest in Alaska drives a regional climate response that promotes growth nearby.



Summer transpiration:
cooling driven cloud formation,
circulation changes,
expansion to the south

