FEBRUARY 24, 2026

Tracking Shifts and Uncertainty in Global Climate Space

Holdridge Life Zones across the CESM Large Ensemble

Adrianna Foster
Scientist V

CO- AUTHORS: Gordon Bonan, Will Wieder, Linnia Hawkins, Isla Simpson, Charlie Koven, & Dave Lawrence

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How do ecosystems change when climate changes?

The climate – ecosystem question

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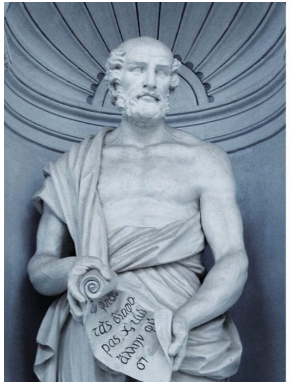
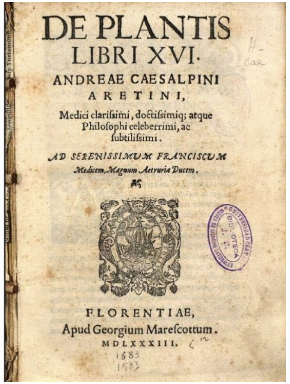
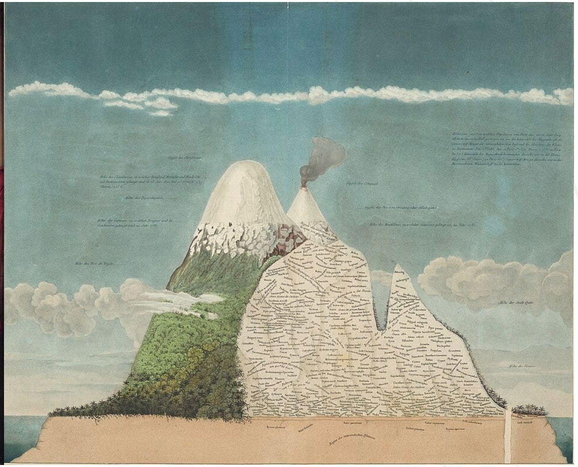




DE PLANTIS
LIBRI XVI.
ANDREAE CAESALPINI
ARETINI,
Medici clarissimi, doctissimiq; atque
Philosophi celeberrimi, ac
subtilissimi.
AD SERENISSIMUM FRANCISCUM
Medicem, Magnum Aetruriae Ducem.
FLORENTIAE,
Apud Georgium Marescottum.
MDLXXXIII.

Theophrastus; 3rd century BC



Alexander Von Humboldt; early 19th century

The climate – ecosystem question

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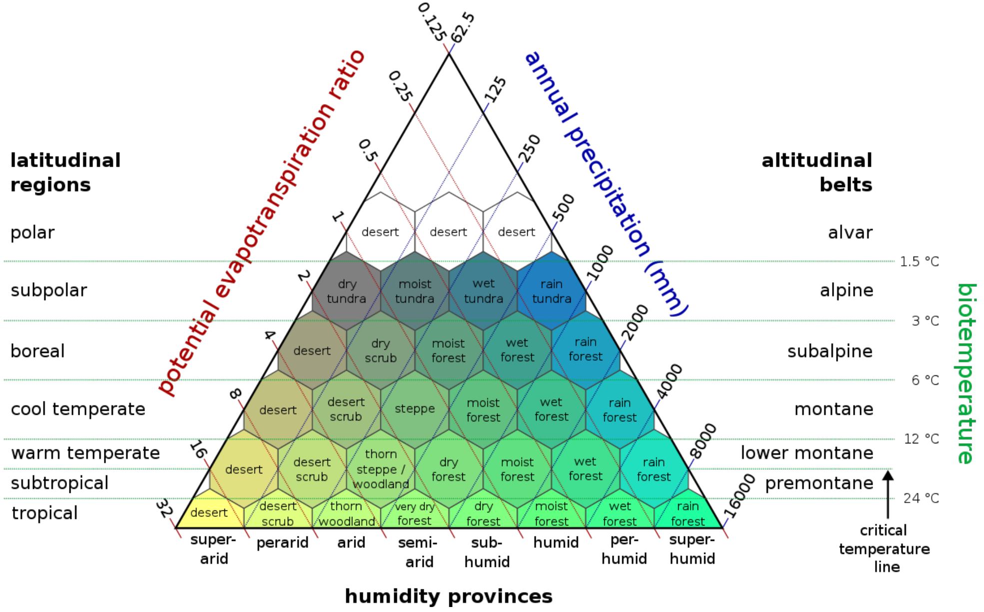
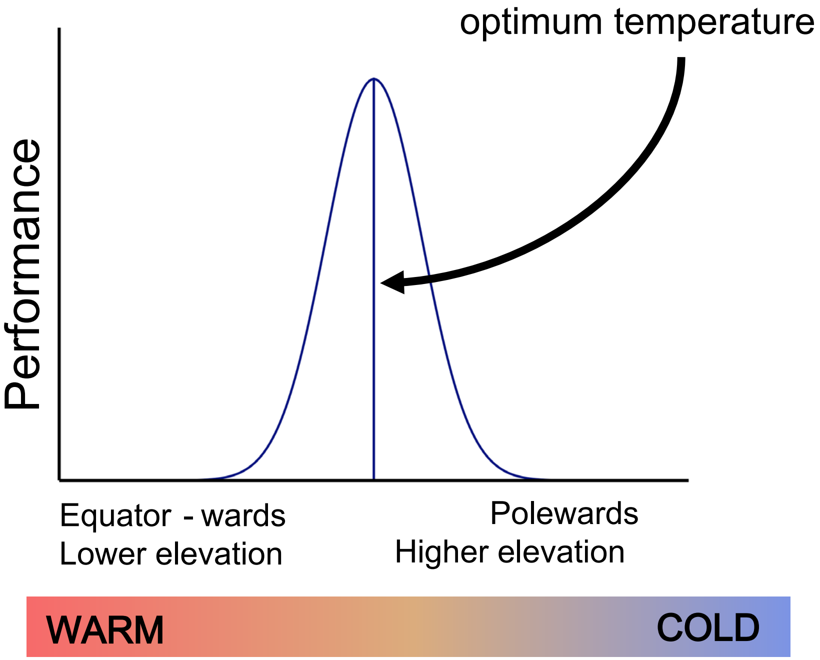
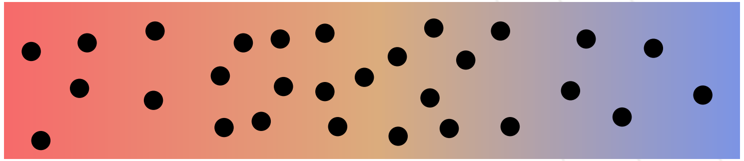
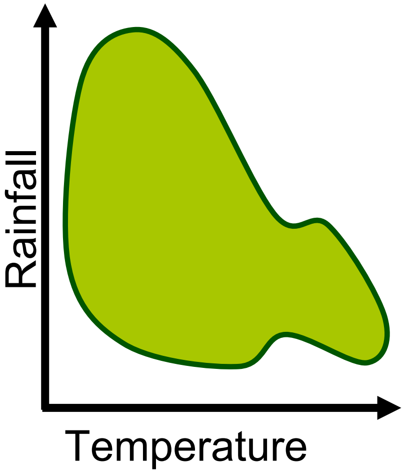


Holdridge Life Zones; 1967

Climate space

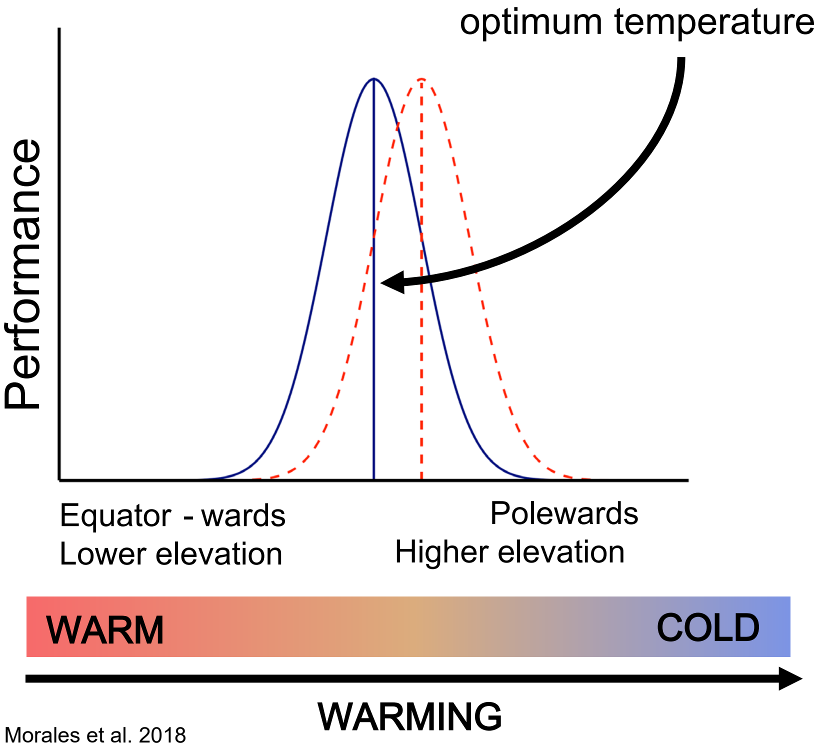


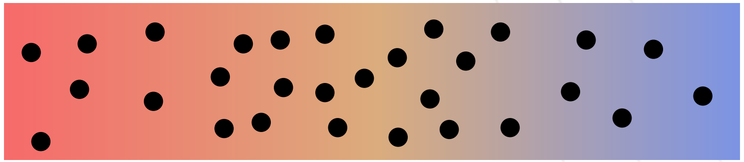


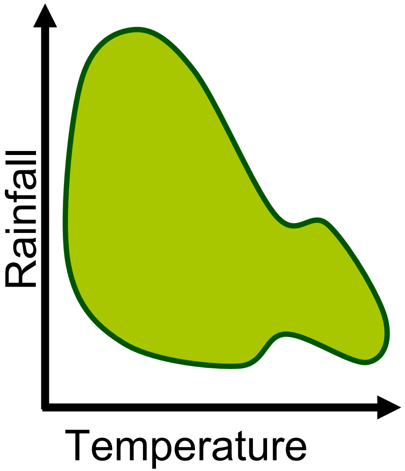


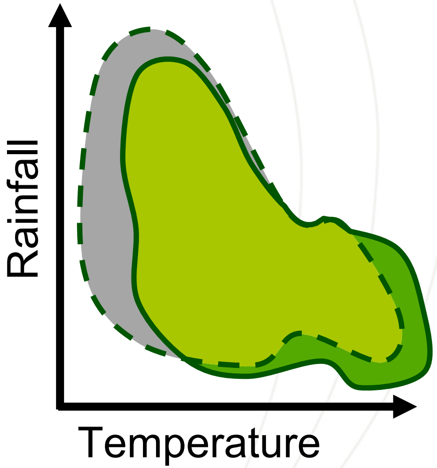
Brito - Morales et al. 2018
Ohlemüller 2011

Climate space









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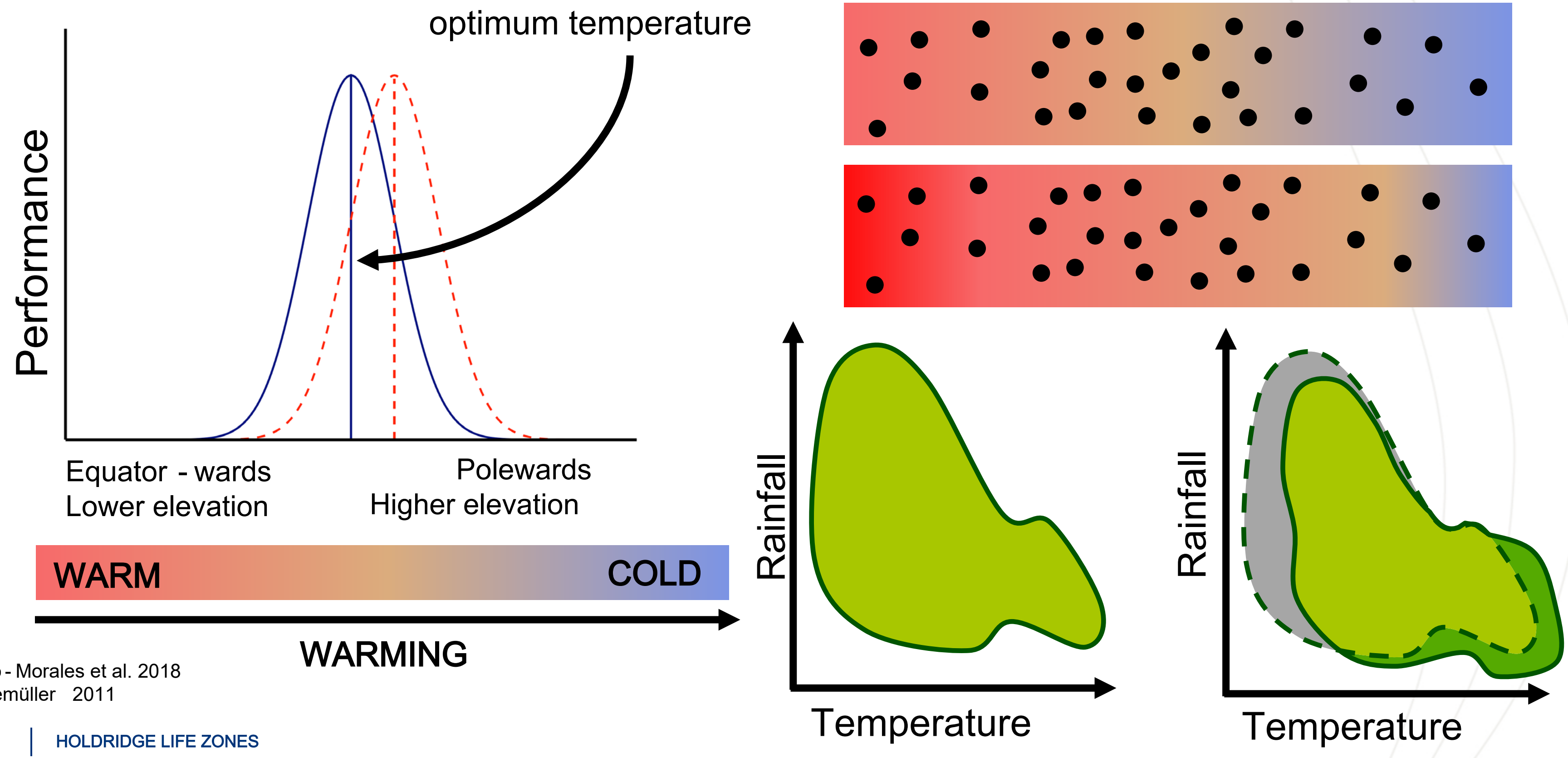

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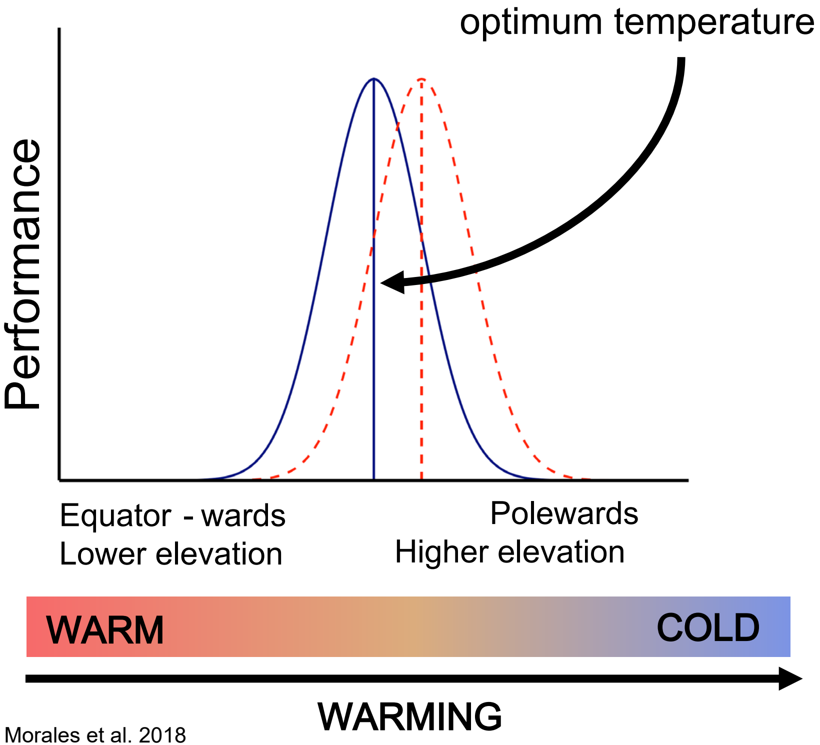

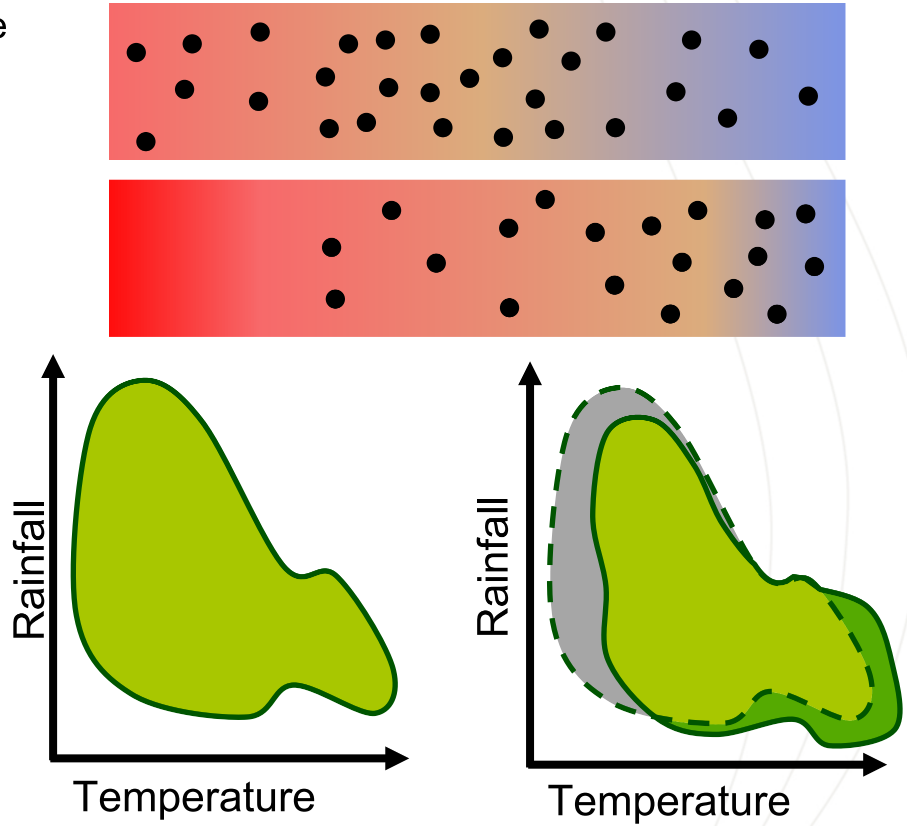

Brito - Morales et al. 2018
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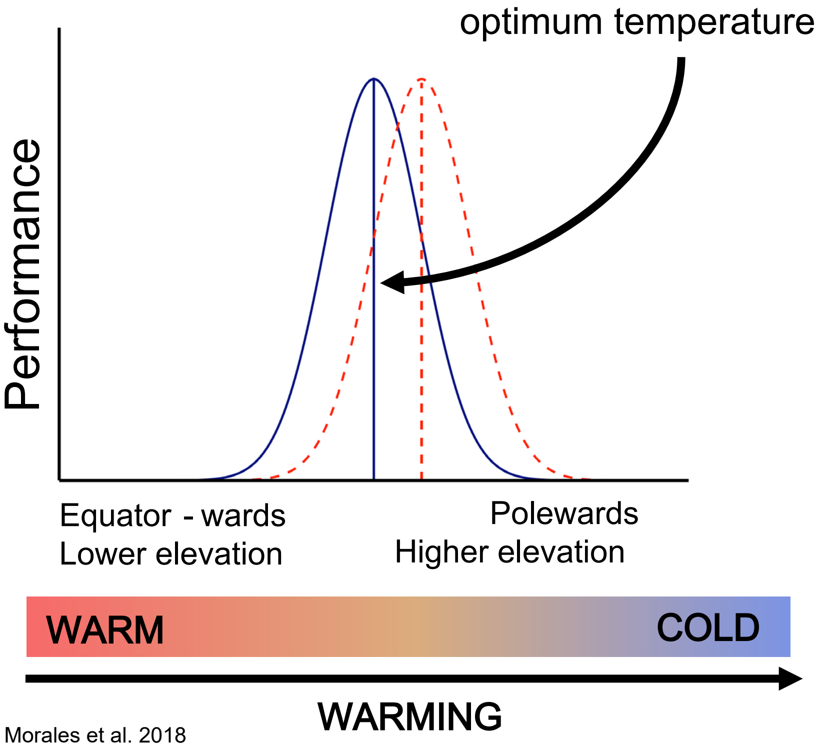

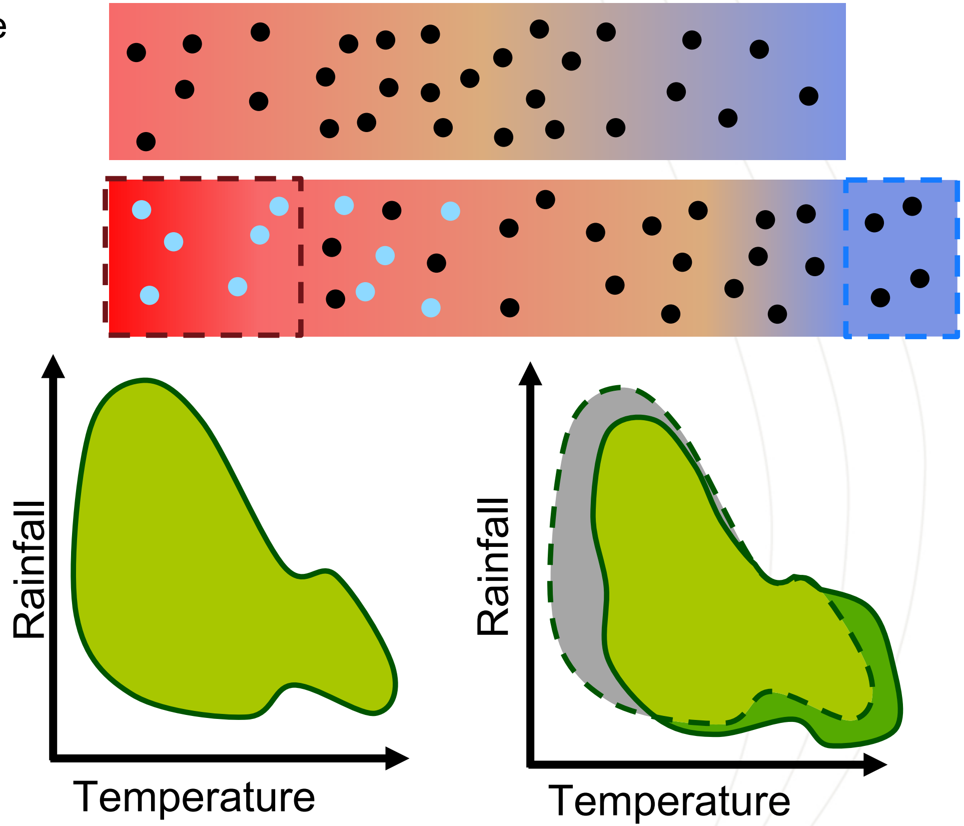

Brito - Morales et al. 2018
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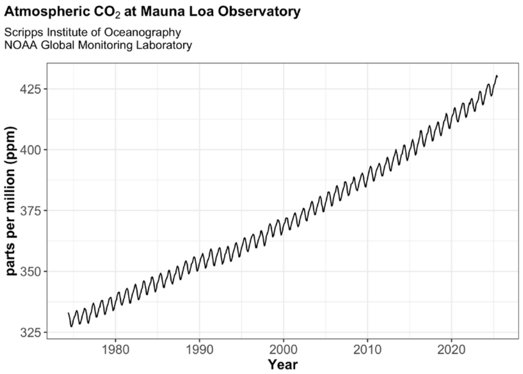
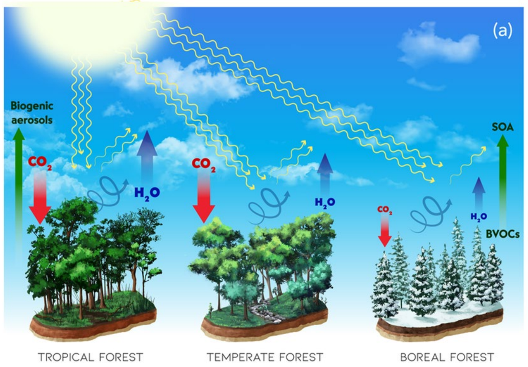
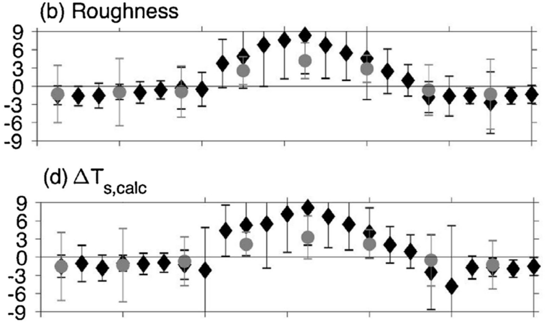
A focus on vegetation



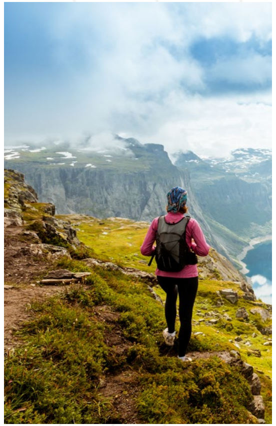




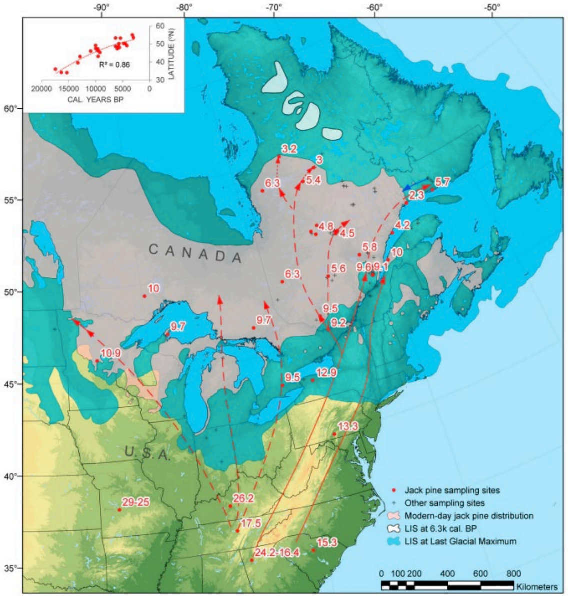








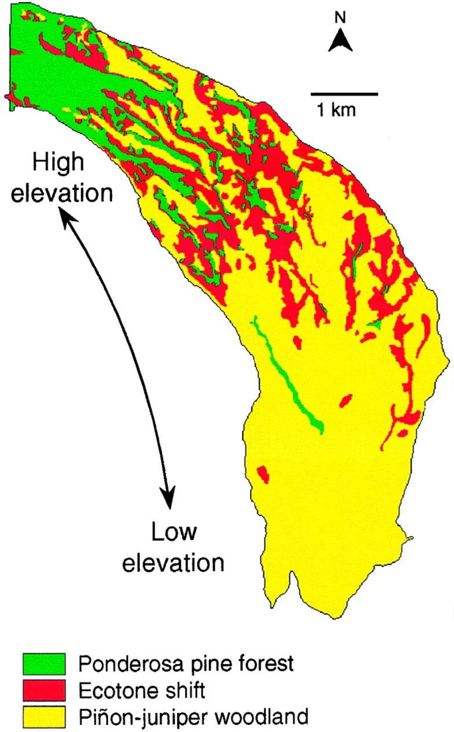
Evidence of species migration



Payette et al. 2022

White spruce tree in the tundra; *Roman Dial*

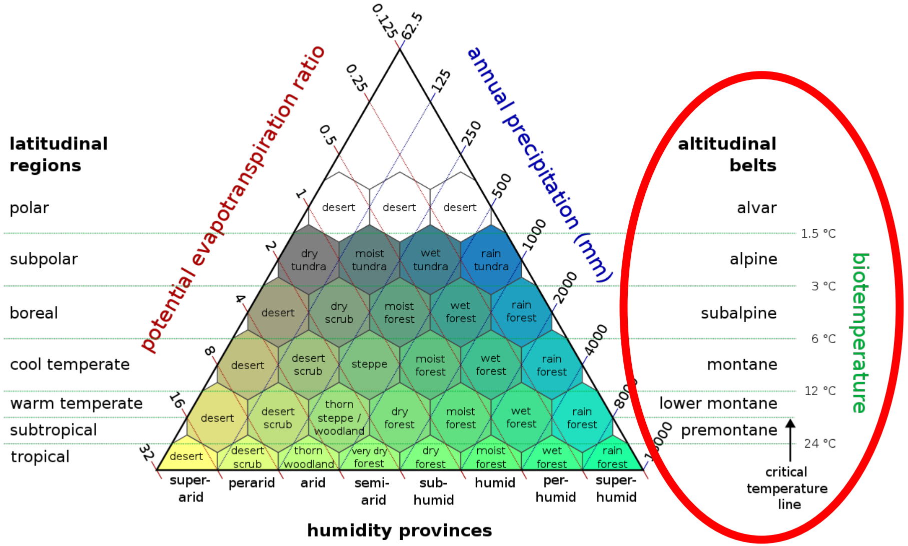
Boreal browning near Dunvegan, Alberta; *Devin Letourneau*

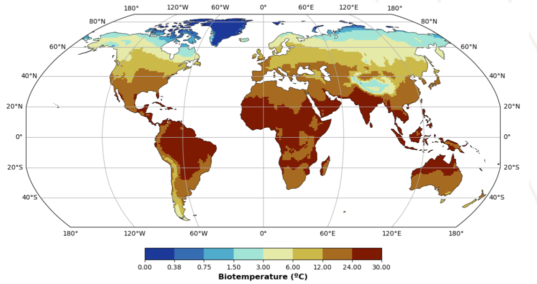


Allen & Breshears 1998

Goal: Quantify potential shifts in biomes and climate space using Holdridge Life Zones as a structured framework

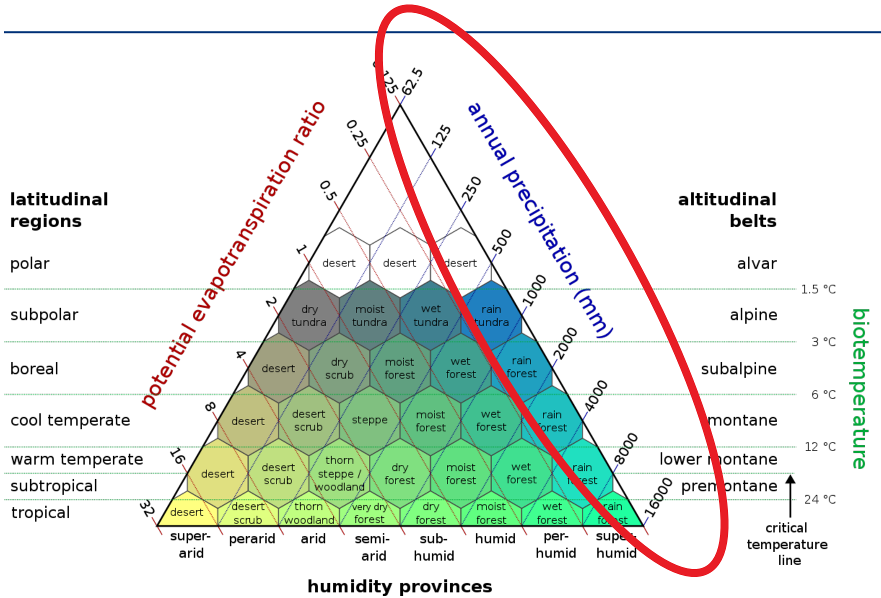
Holdridge Life Zones as climate space

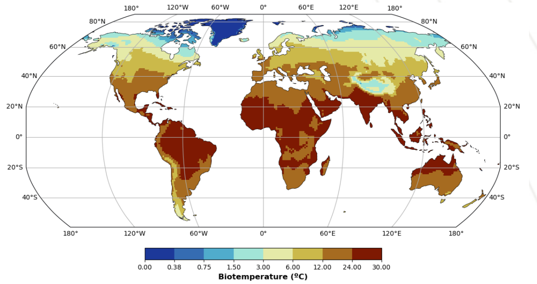


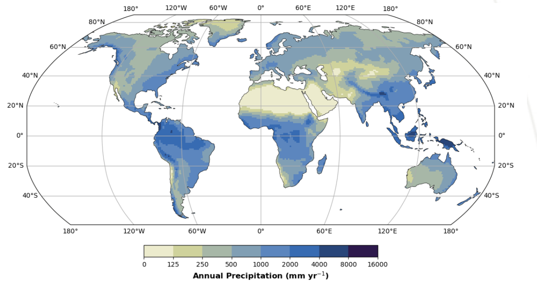


Biotemperature : Average annual temperature, capped from 0º to 30ºC

Holdridge Life Zones as climate space



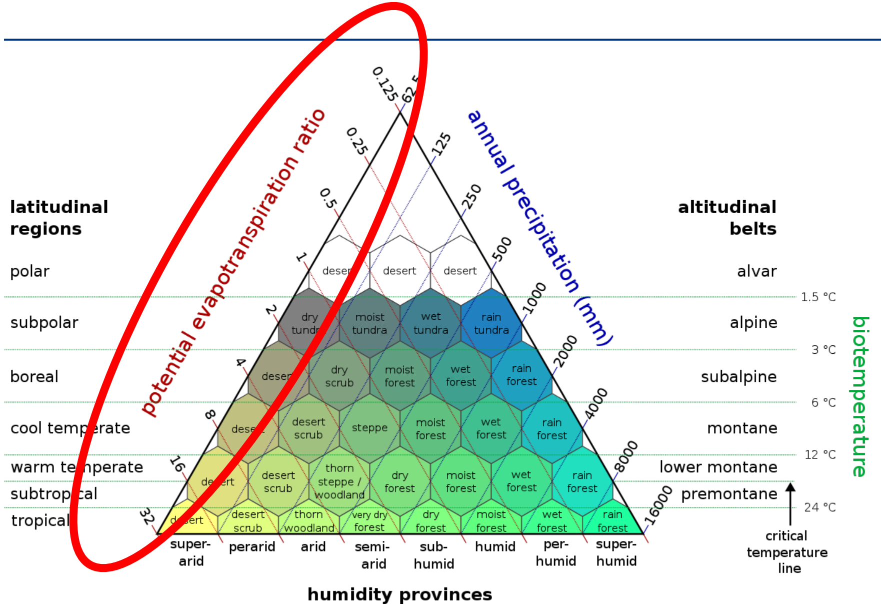




Biotemperature : Average annual temperature, capped from 0º to 30ºC

Precipitation: Average annual precipitation (mm/yr) :

Holdridge Life Zones as climate space



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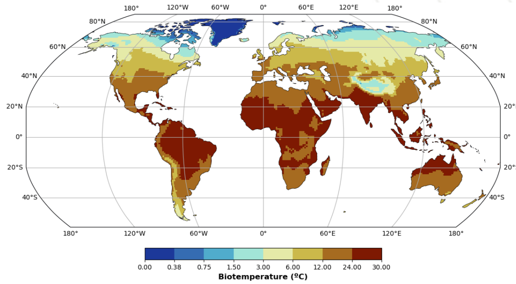
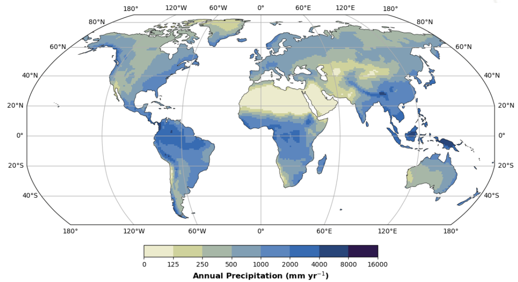
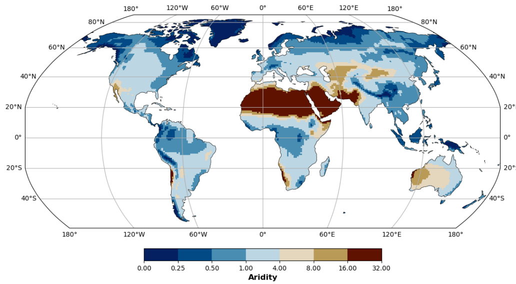
Precipitation: Average annual precipitation (mm/yr) :

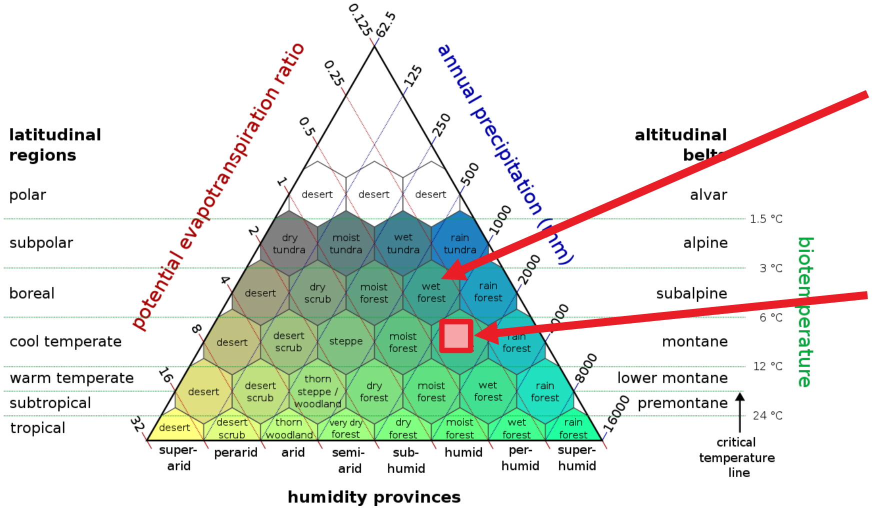
Aridity Index: PET/Precipitation







Classifying Holdridge Life Zones



Boreal wet forest

Biotemperature : 4.24ºC
Precipitation: 707 mm/yr
Aridity: 0.354

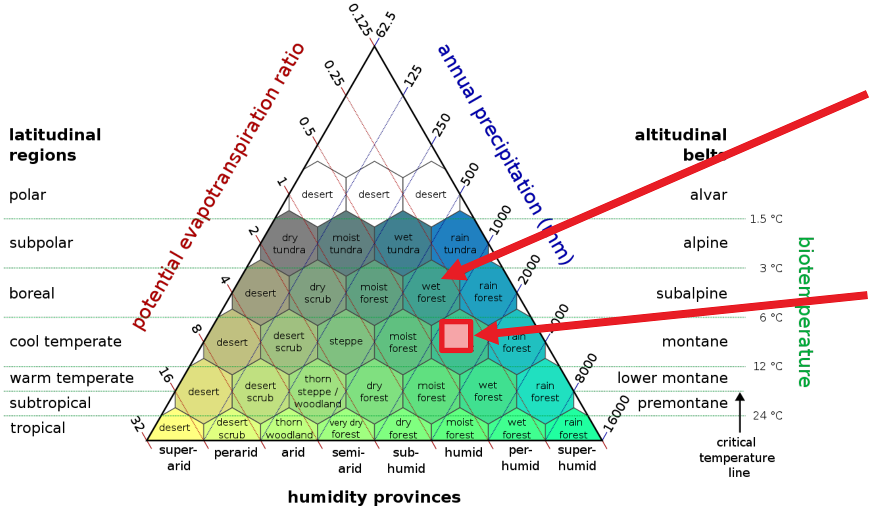
Cool temperate wet forest

Biotemperature : 8.49ºC
Precipitation: 1414 mm/yr
Aridity: 0.354

$$(T_{B_i} - T_{B_j}) \quad (P_i - P_j) \quad (A_i - A_j)$$

$$(\log_2 T_{B_i} - \log_2 T_{B_j}) + (\log_2 P_i - \log_2 P_j) + (\log_2 A_i - \log_2 A_j)$$

Classifying Holdridge Life Zones



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Precipitation: 1414 mm/yr
Aridity: 0.354

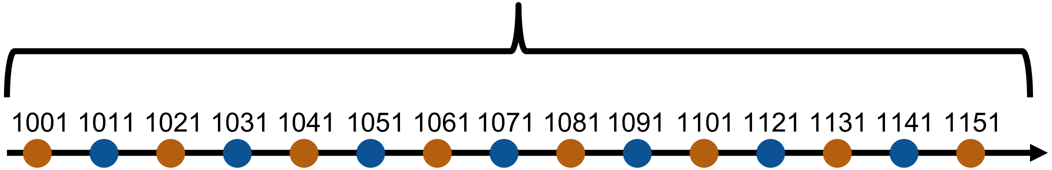
$$\sqrt{(\log_2 T_{B_i} - \log_2 T_{B_j})^2 + (\log_2 P_i - \log_2 P_j)^2 + (\log_2 A_i - \log_2 A_j)^2}$$

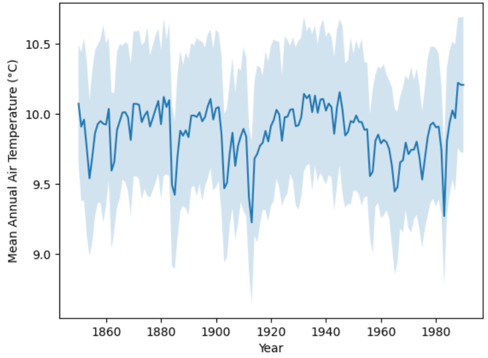
Minimize Euclidean distance with hexagon centroids

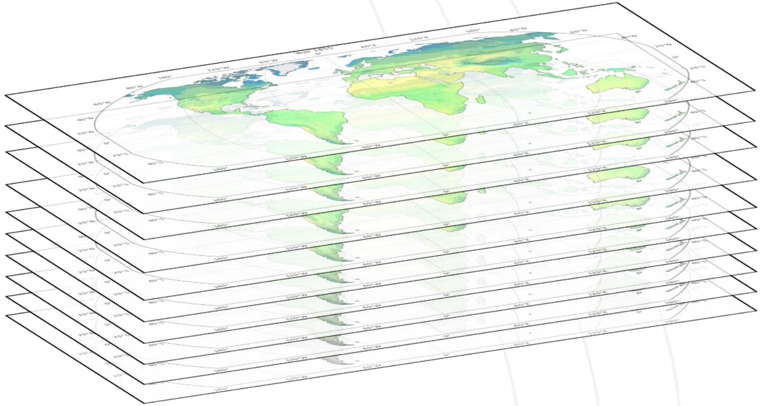
Application to CESM LENS

LENS2– Macro Perturbation Design

20 members
10 standard
10 MOAR+COSP
(10- year interval starts from PI Control)







⋮

n = 90

Application to CESM LENS

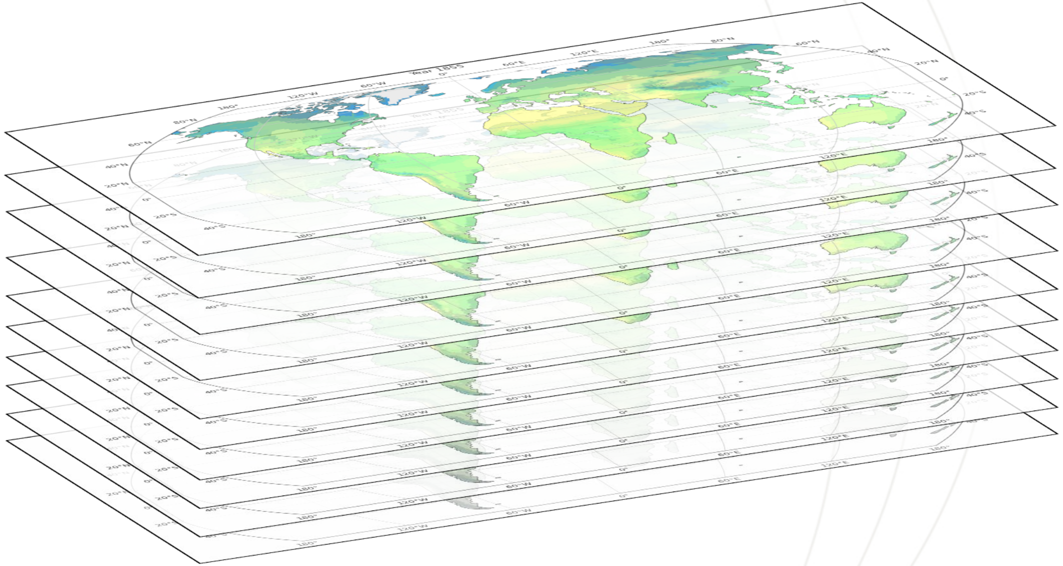
10- yr rolling averages of CESM output

1855 to 2095

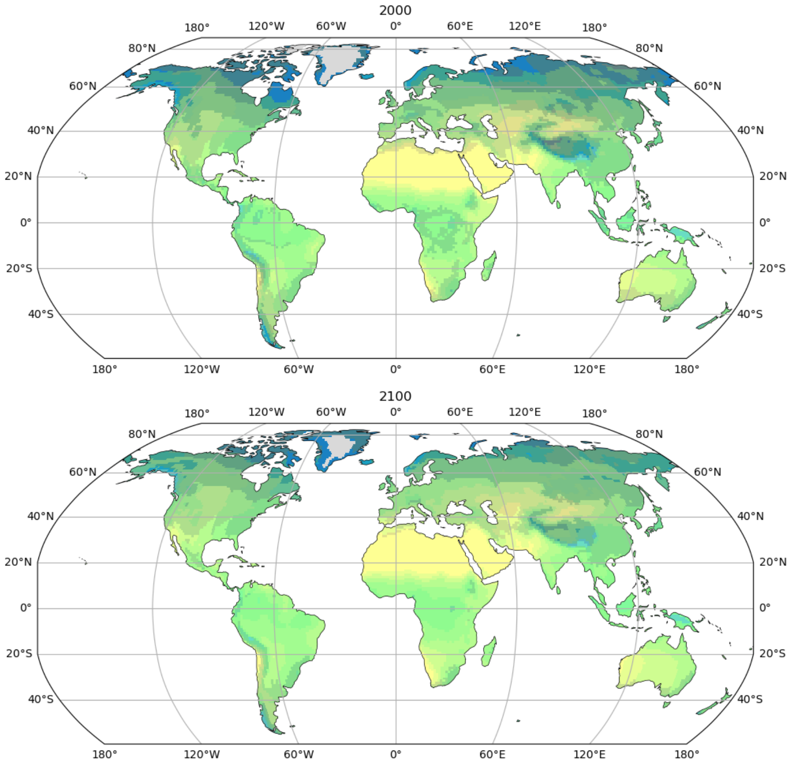
SSP3- 7.0 (original LENS2)
- 90 ensemble members

SSP2- 4.5
- 16 ensemble members

SSP5- 8.5
- 15 ensemble members

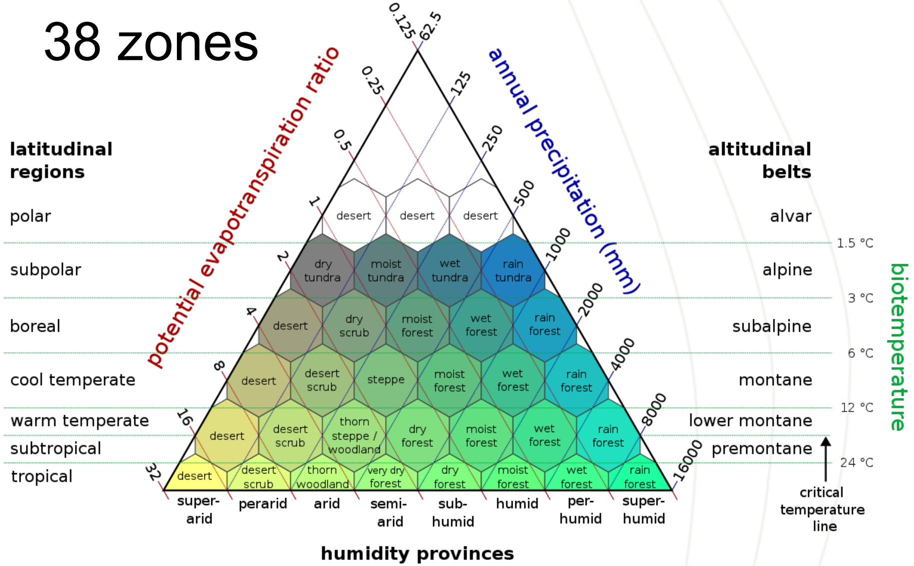


Results – Holdridge Life Zones SSP3

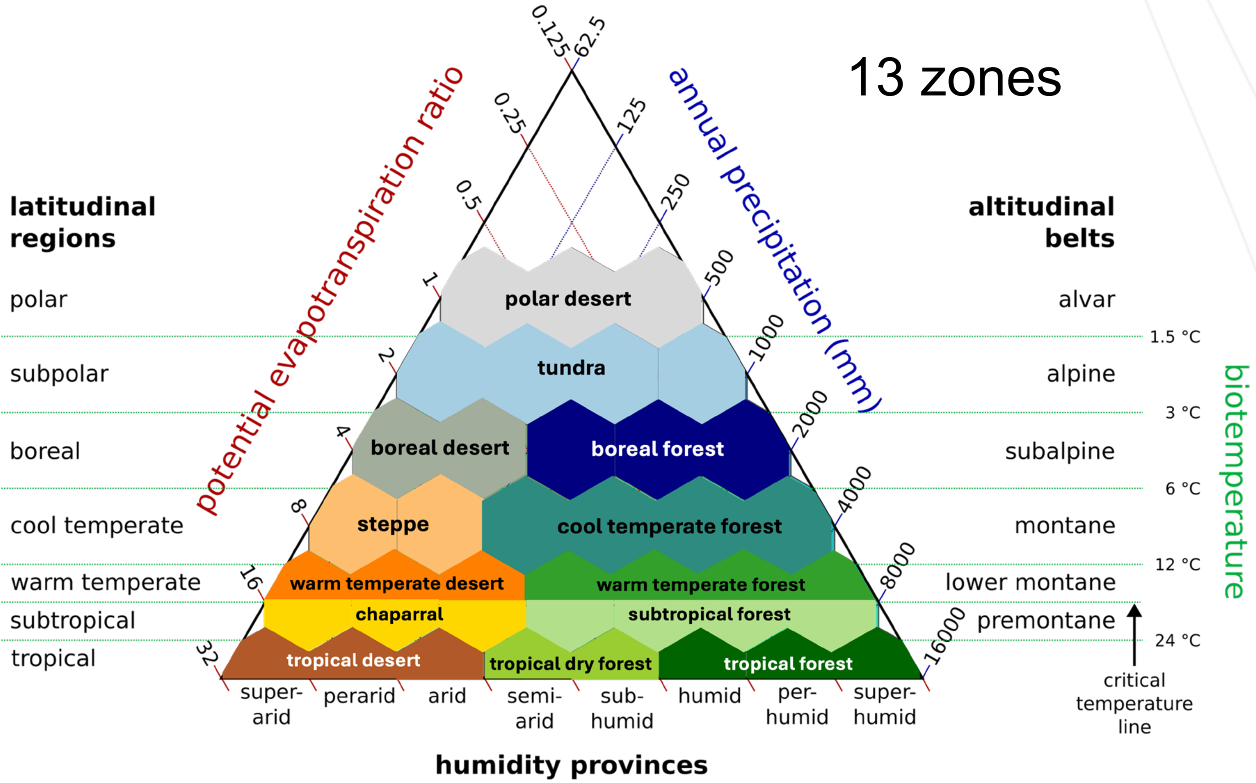


Ensemble average

38 zones



Creating collapsed zones

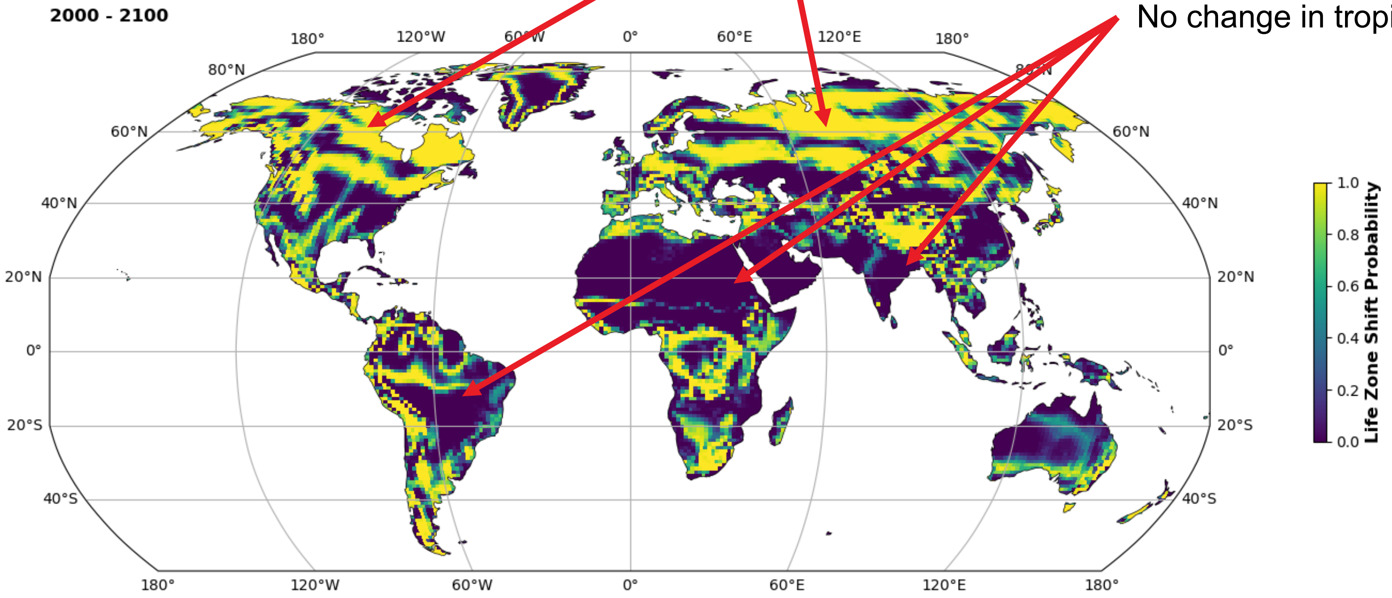


Probability of HLZ shift

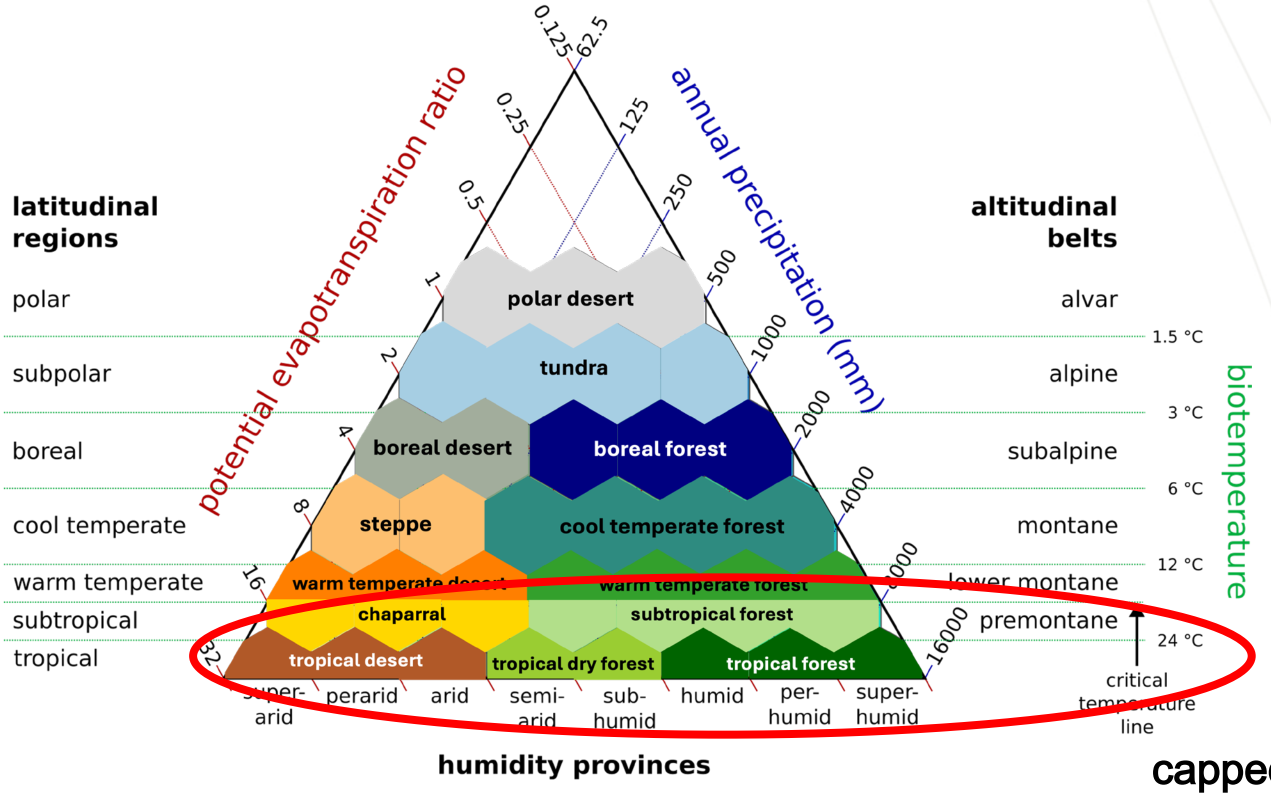
SSP3-7.0 (n=90)
collapsed zone changes

High probability of change in boreal/arctic

No change in tropics?



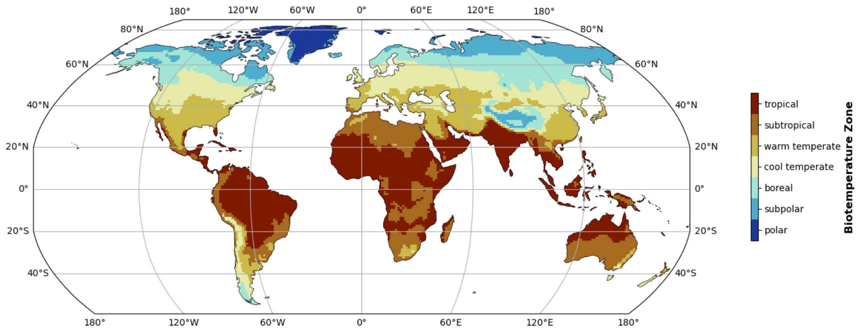
Tropical “stability”



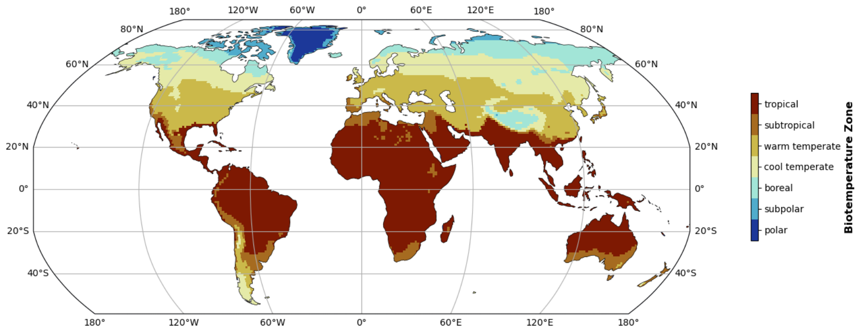
capped at 30ºC

Biotemperature changes

Year 2000 biotemperature zones

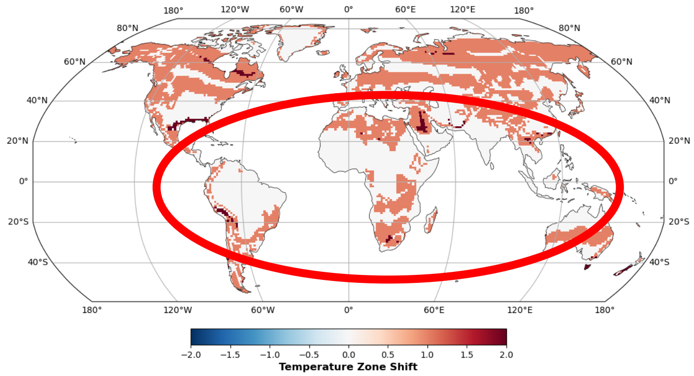


Year 2100 biotemperature zones



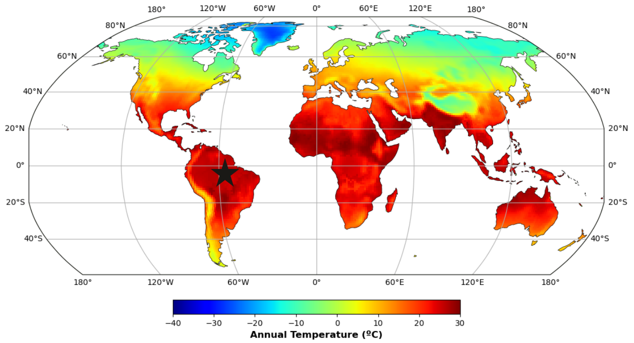
"Tropical" = 24ºC – 30ºC

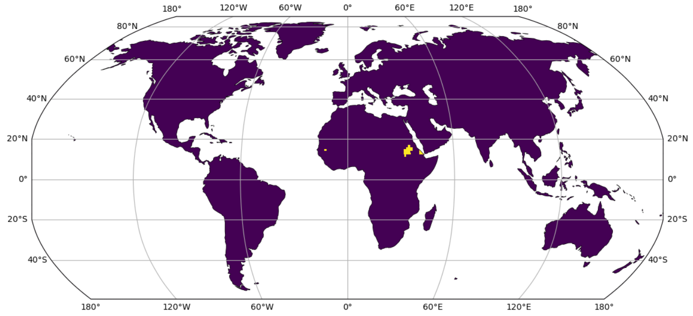
??? = >30ºC

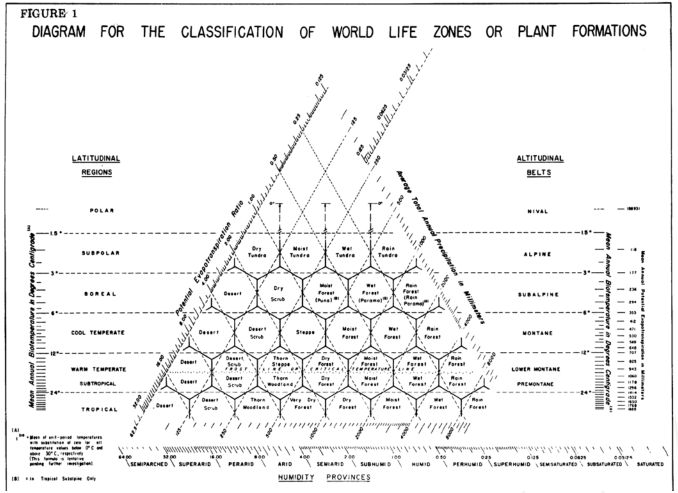


Biotemperature changes

Year 1967 annual temperature



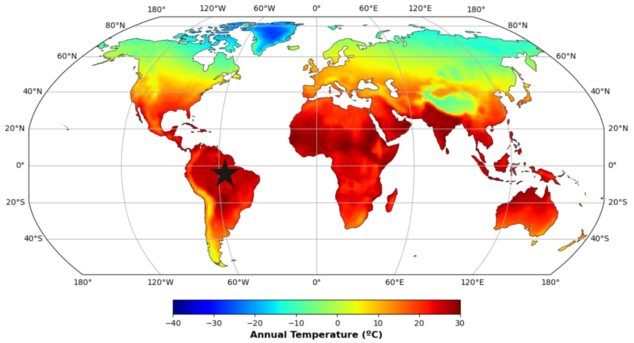


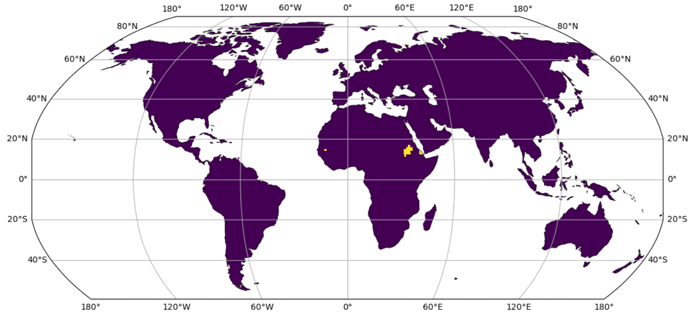


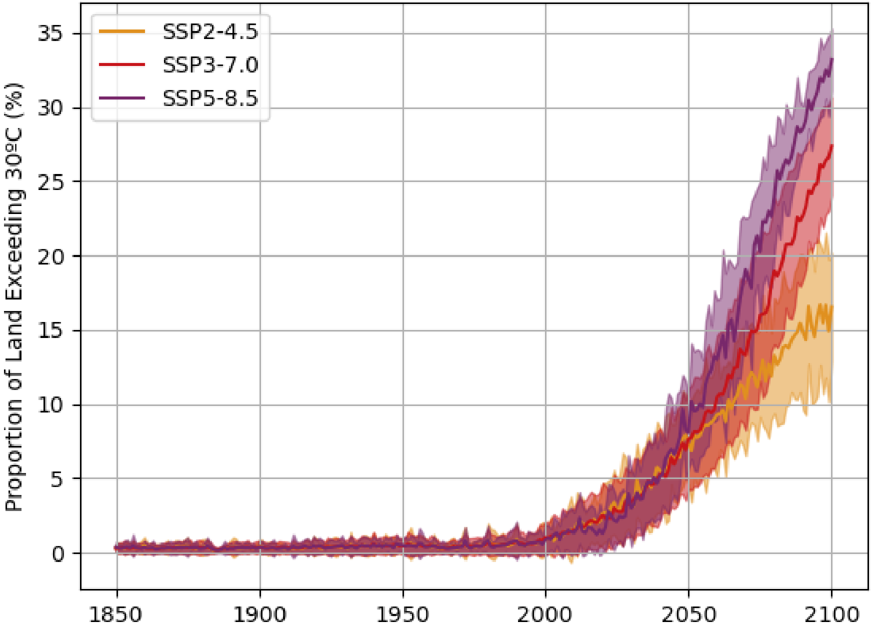
Holdridge (1967)

Biotemperature changes

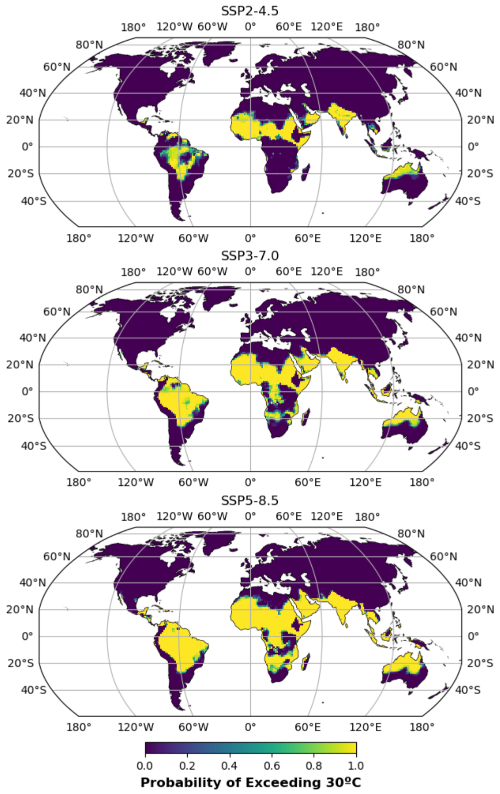
Year 1967 annual temperature

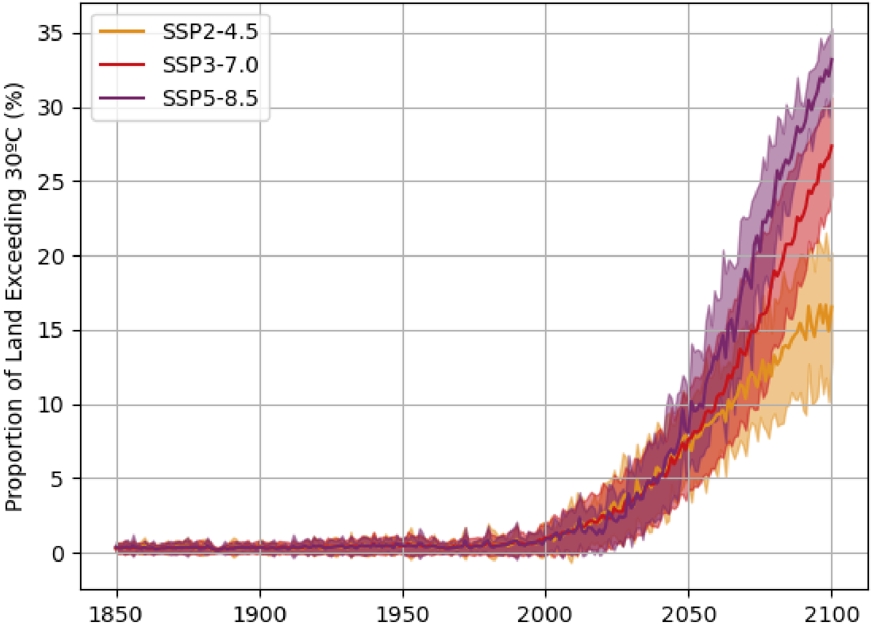




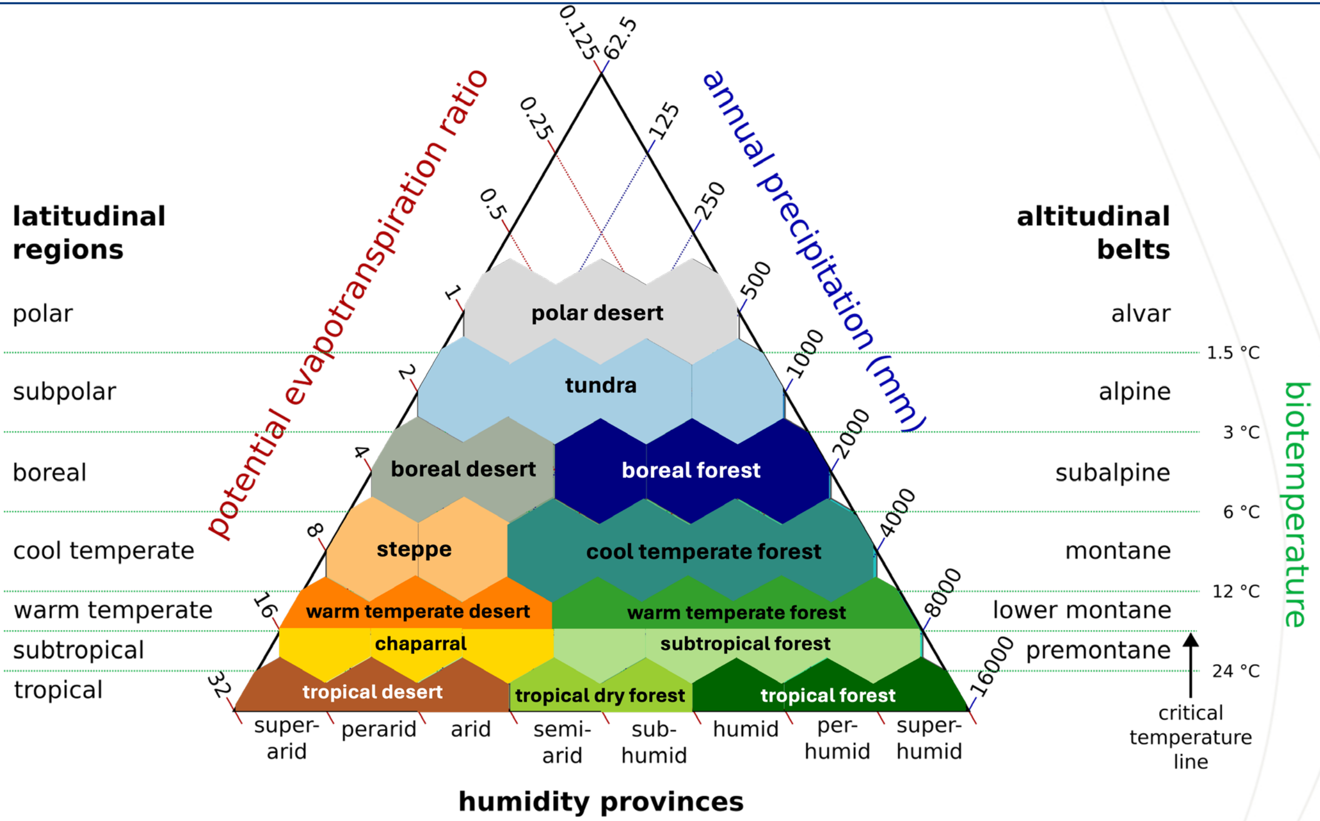


Biotemperature changes

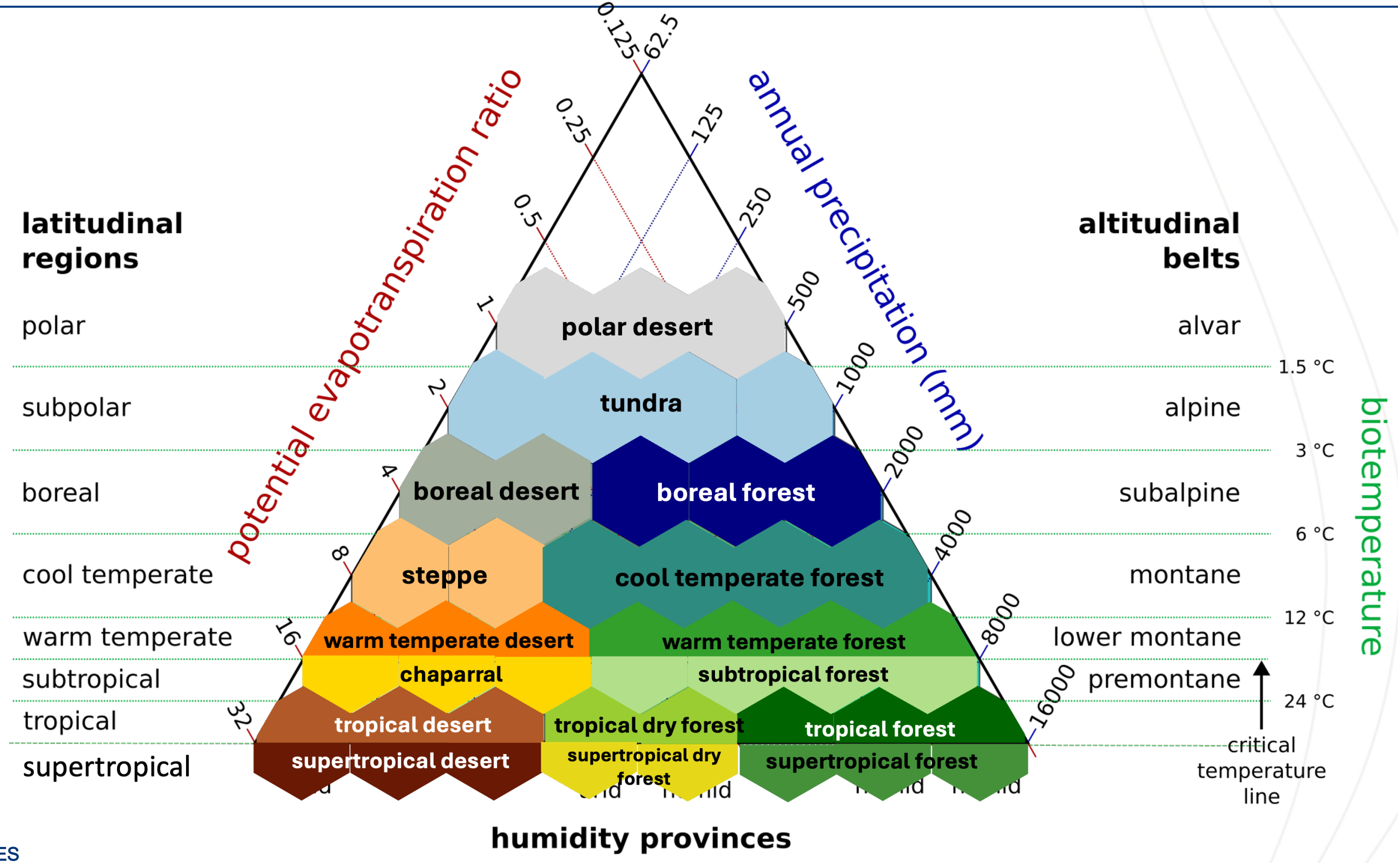




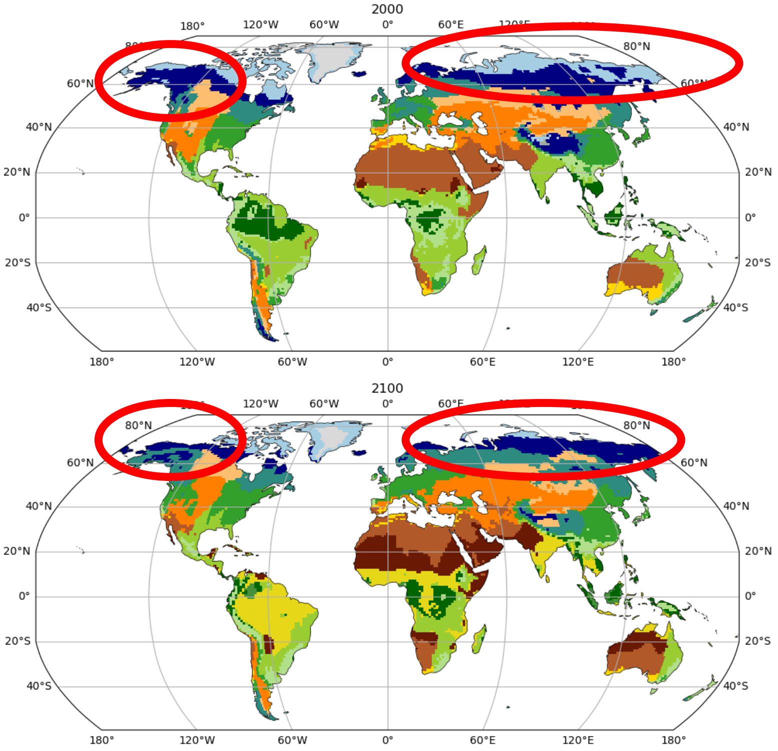
Creating new zones



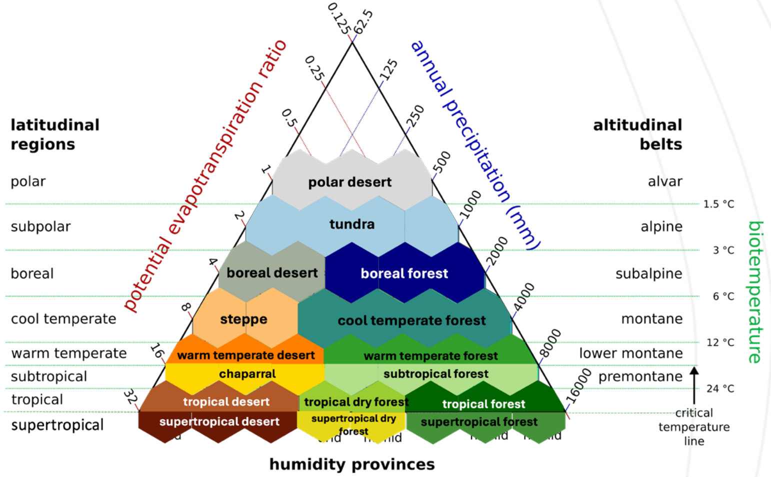
Creating new zones



Results – Holdridge Life Zones SSP3



Ensemble average: SSP3 - 7.0



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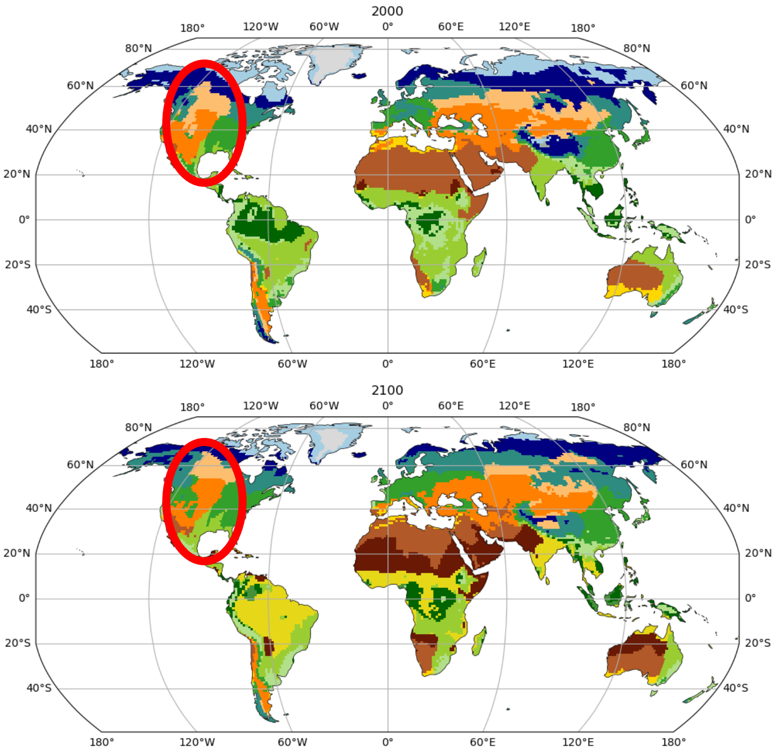

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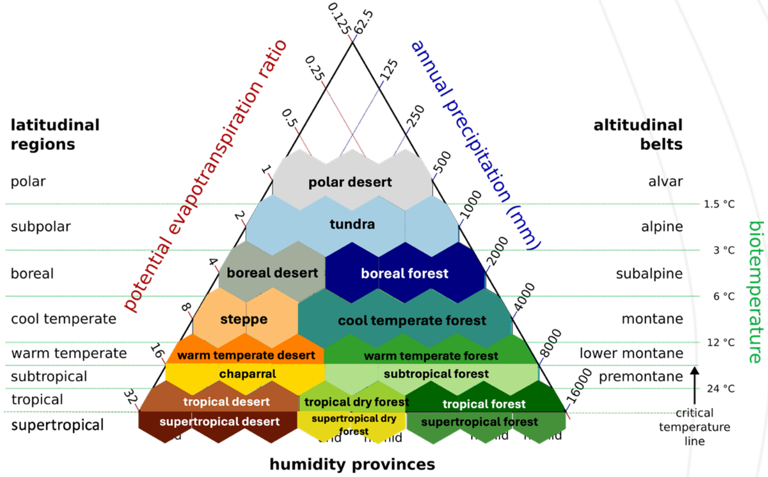

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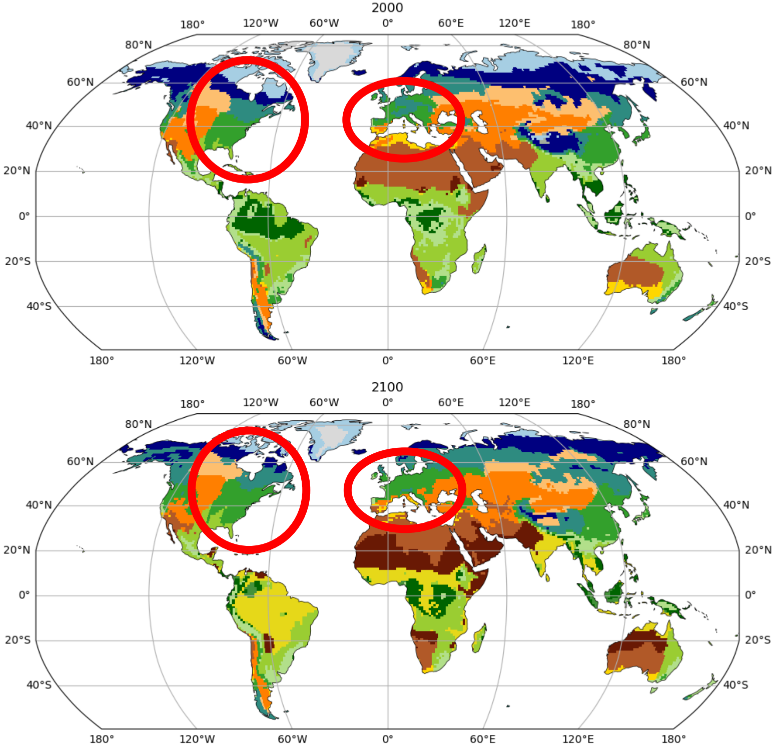

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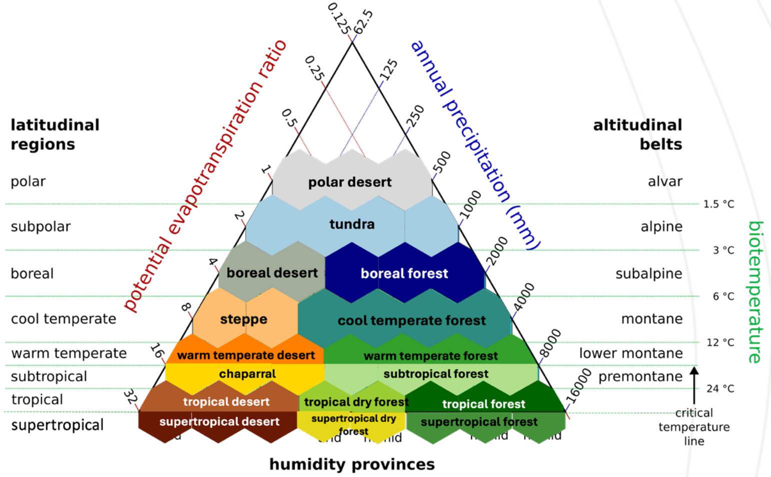
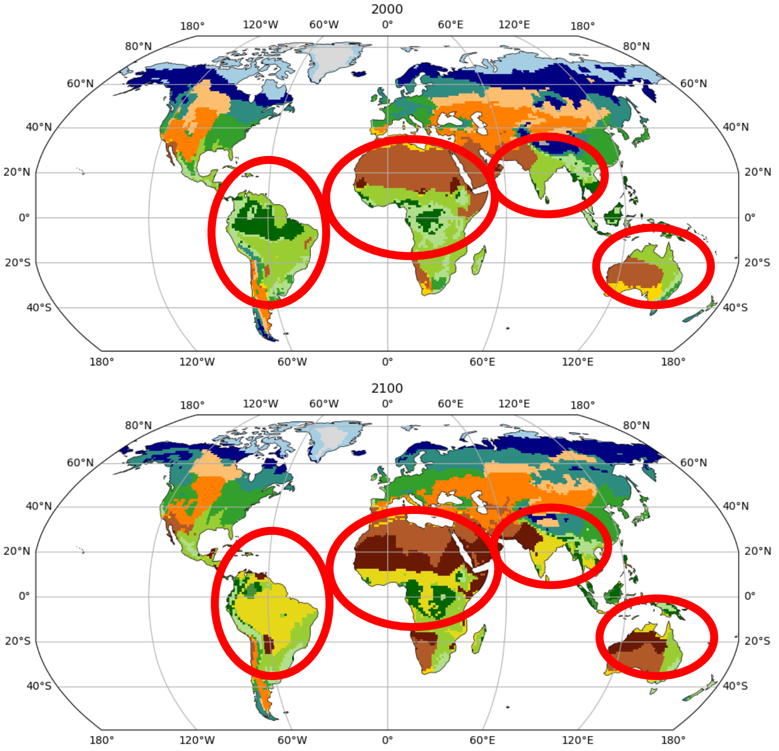
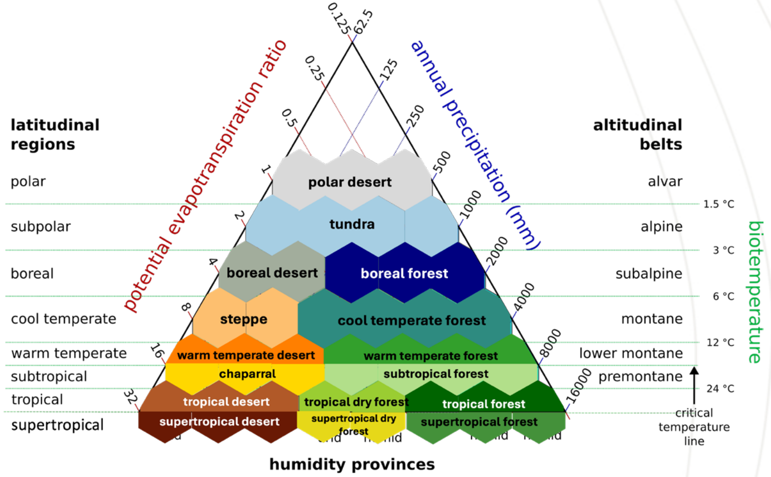


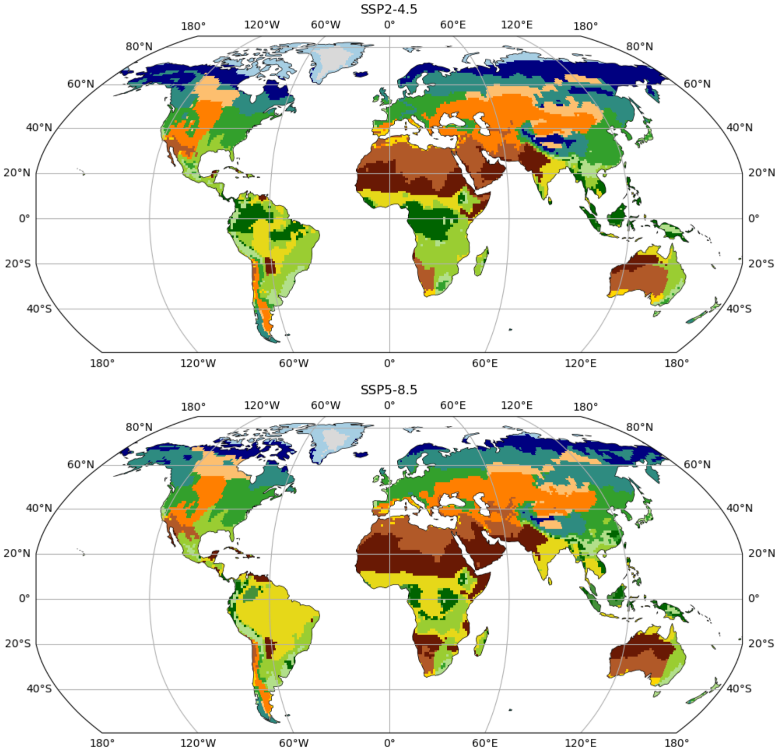
Results – Holdridge Life Zones SSP3

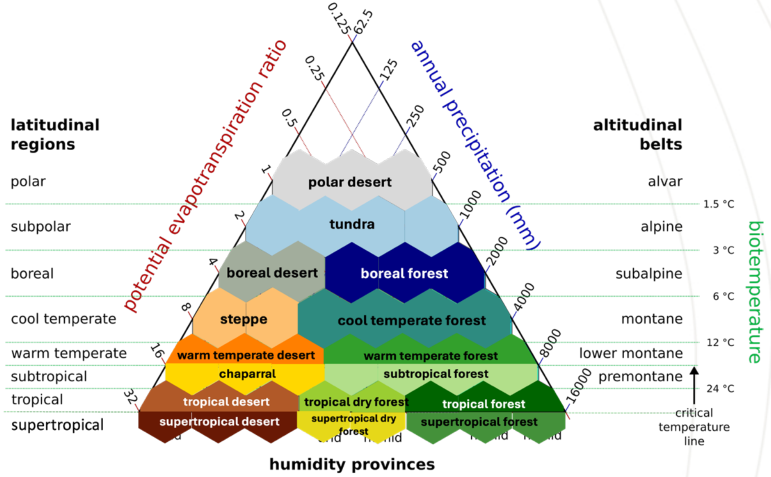


Ensemble average: SSP3 - 7.0

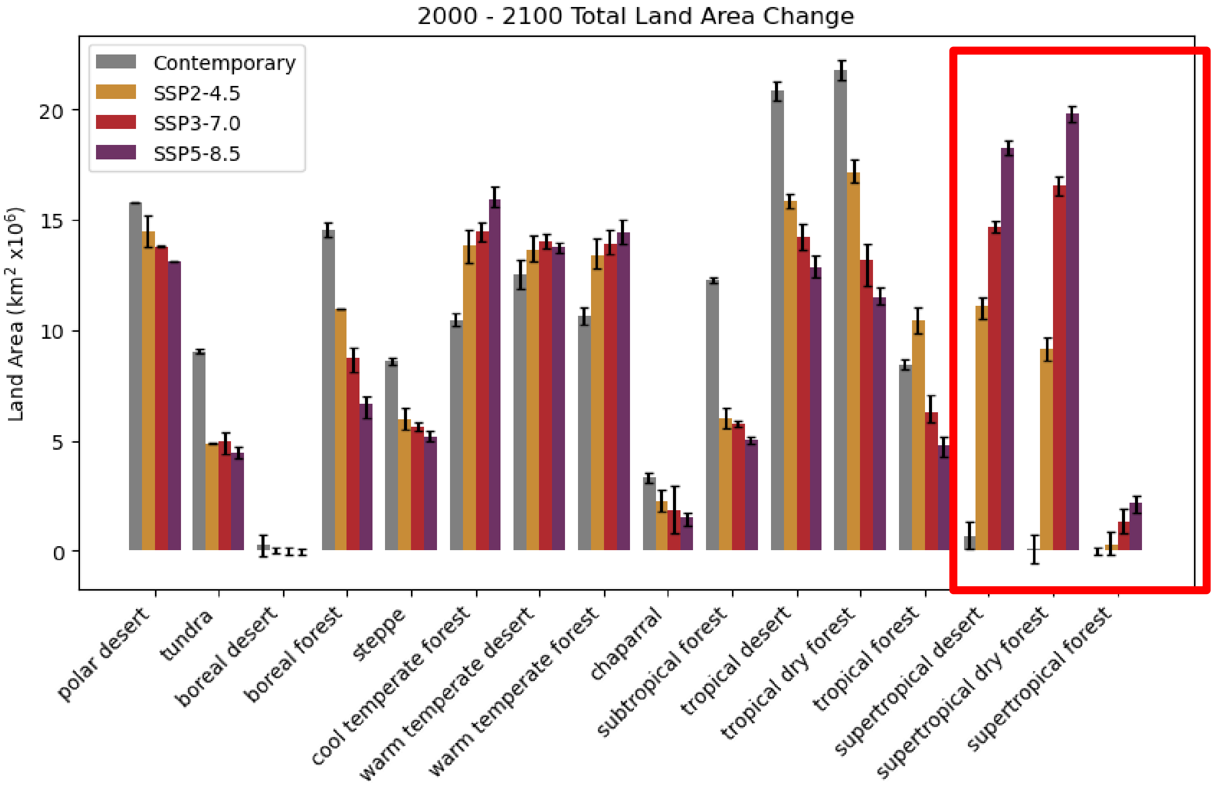


Results – Holdridge Life Zones, other SSPs





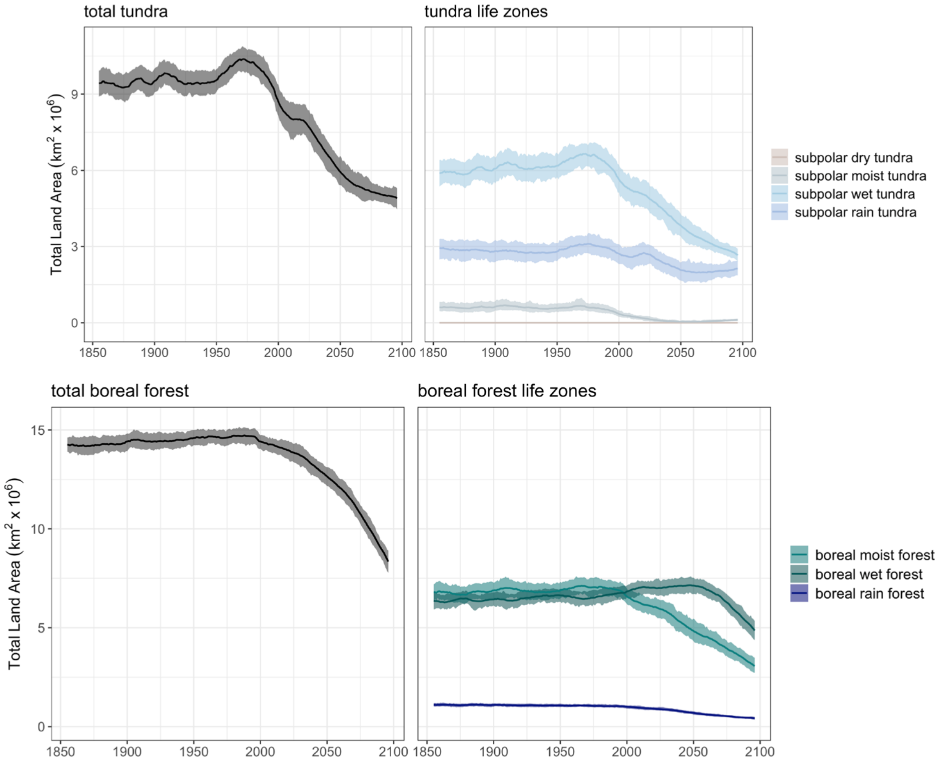
Net land area change

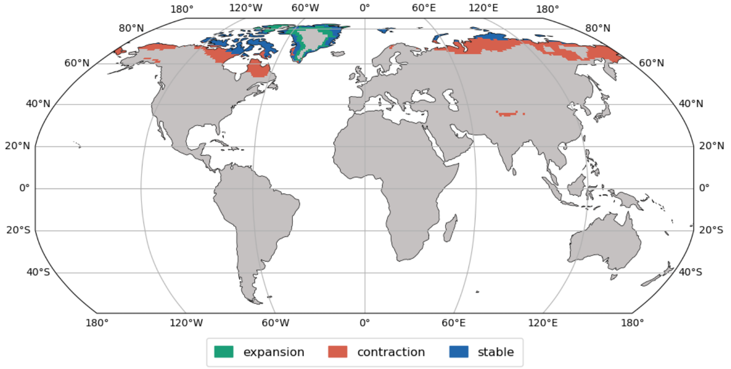


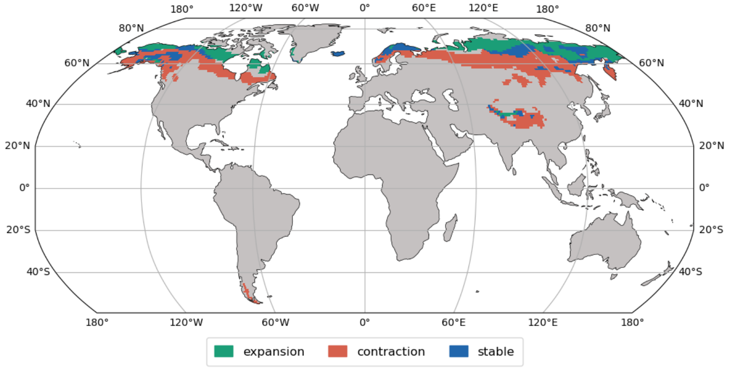
Net gains:
cool temperate forest
warm temperate desert & forest
supertropical biomes
tropical forest (SSP2 only)

Net losses:
tundra
boreal forest
steppe
chaparral
tropical desert & dry forest
tropical forest (SSPs 3 & 5)

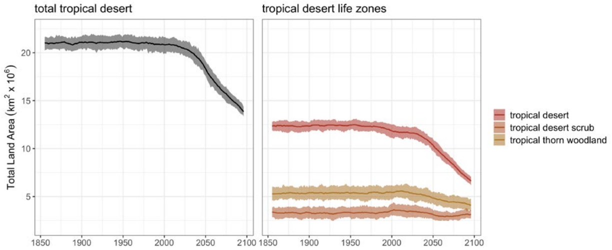
Net land area change – tundra & boreal

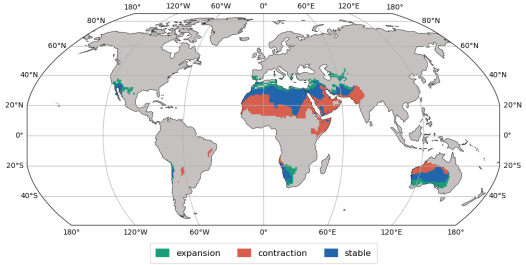


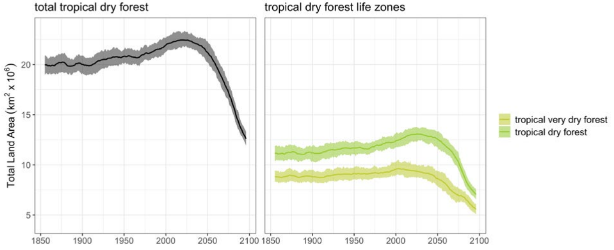


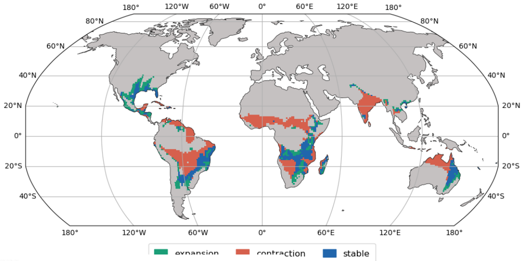


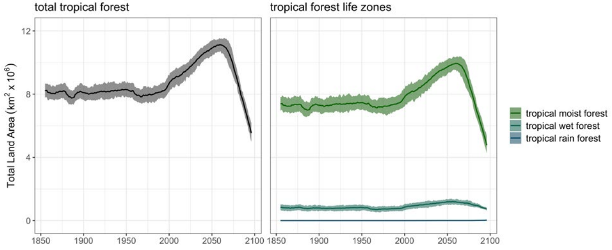
Net land area change – tropical

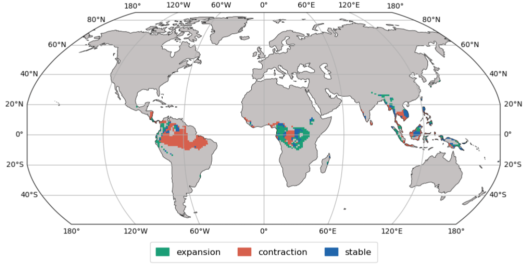




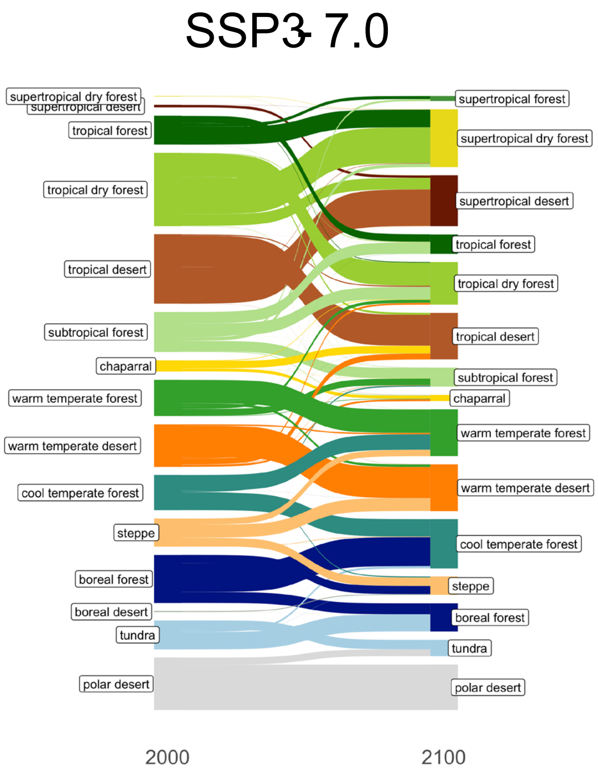








How are biomes shifting?

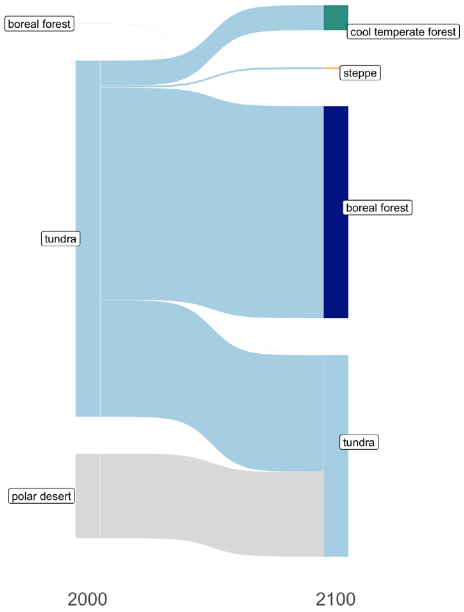


~55% of landscape transitions

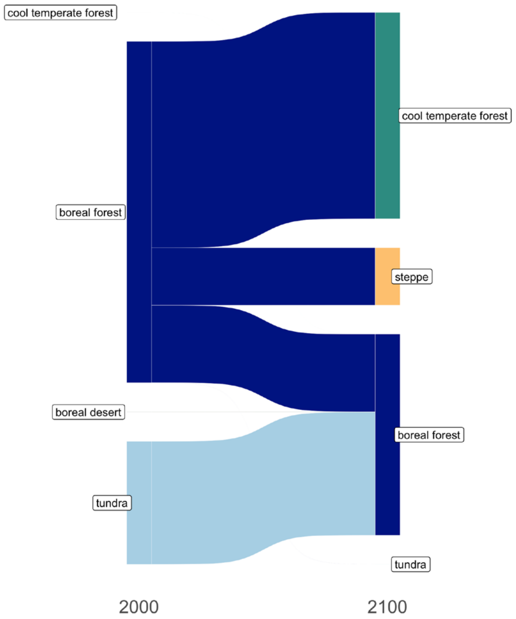
HOLDRIDGE LIFE ZONES

How are biomes shifting?

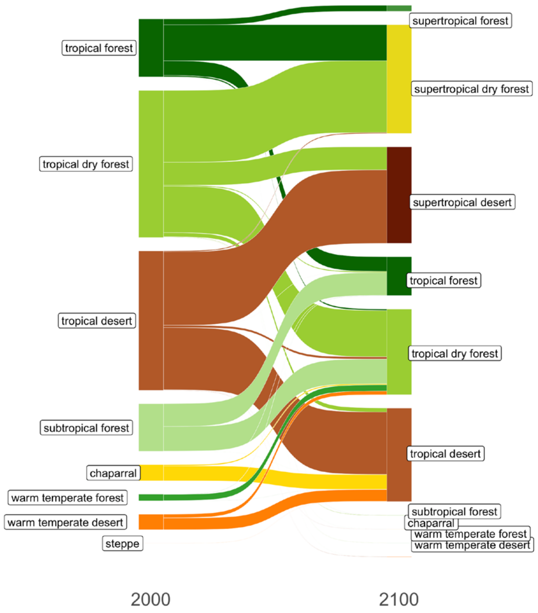
Tundra



Boreal

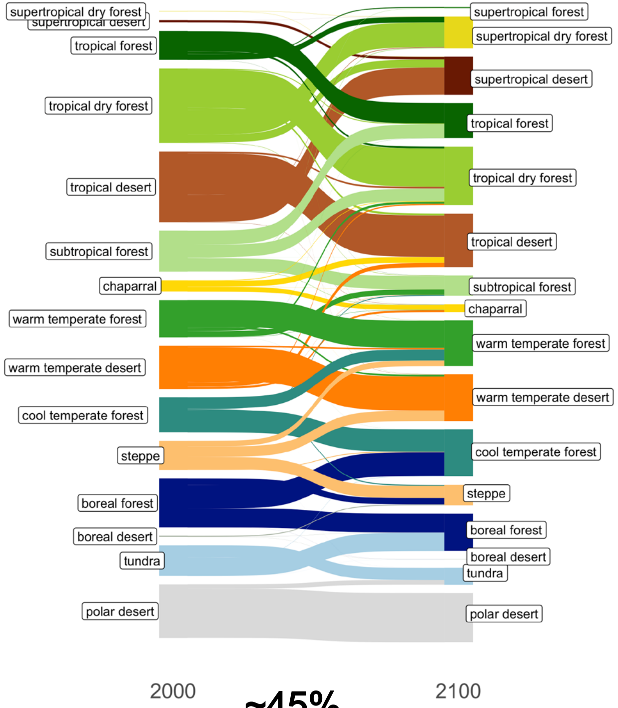


Tropical



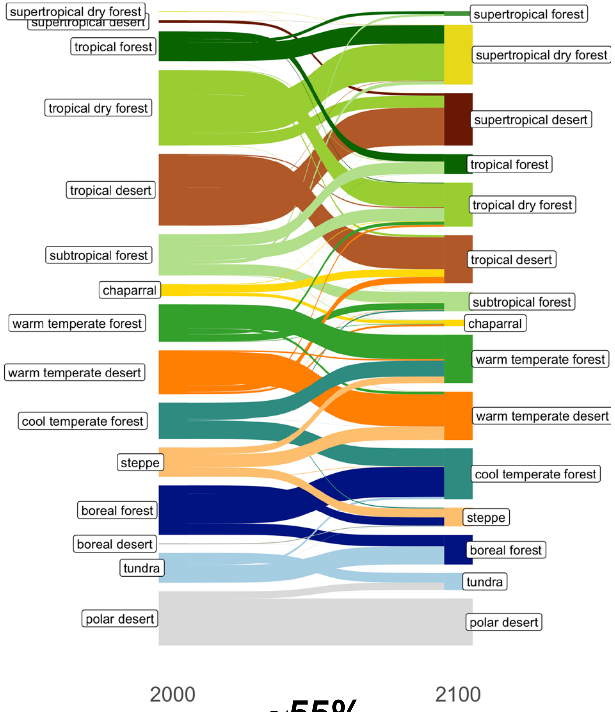
How are biomes shifting?

SSP2 4.5



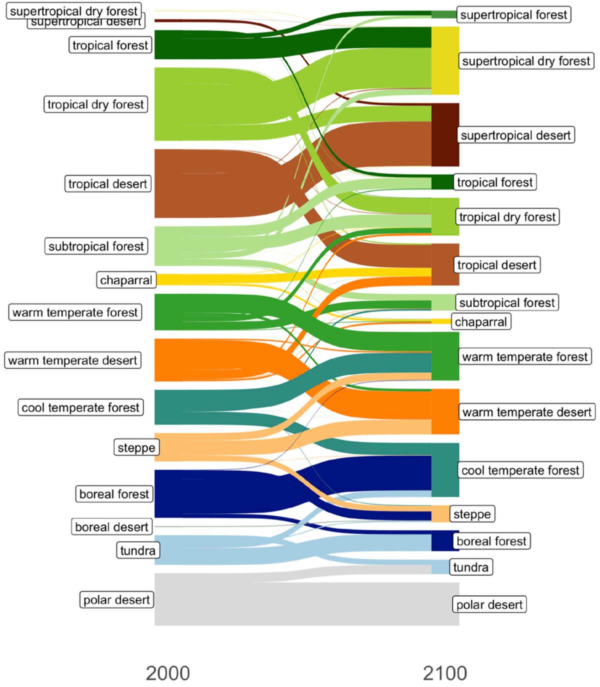
~45%

SSP3 7.0



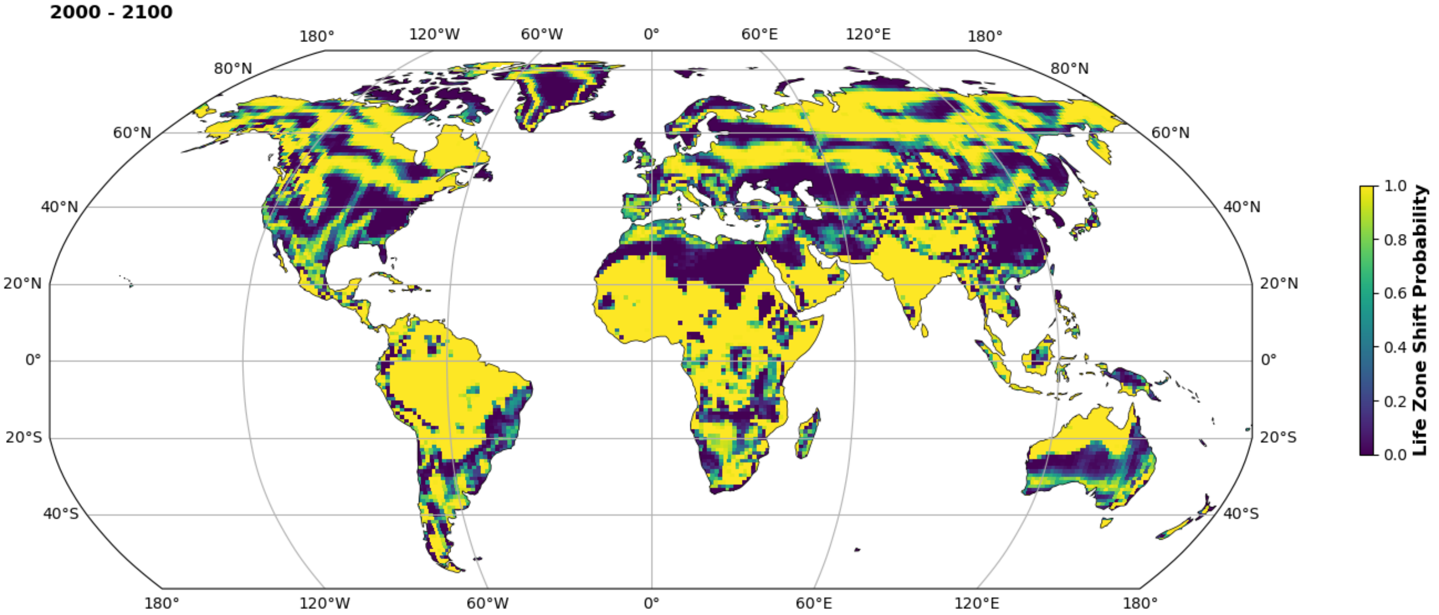
~55%

SSP5 8.5



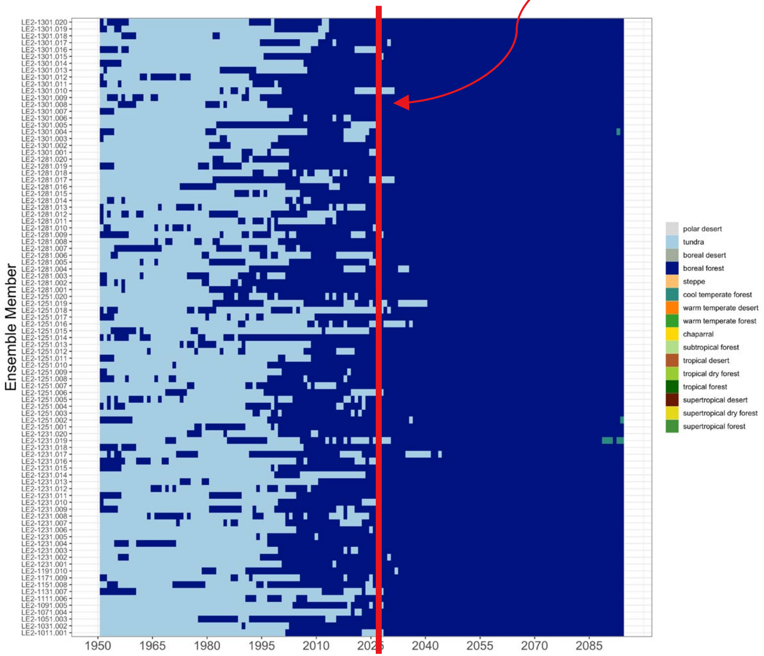
~65%

Probability of shifting by 2100

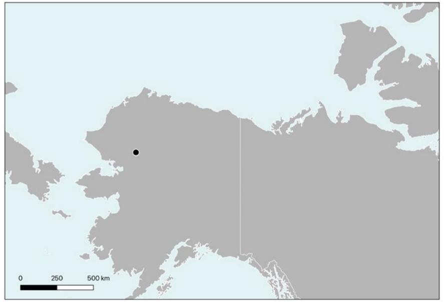


Timing of biome shifts

Brooks Range, AK



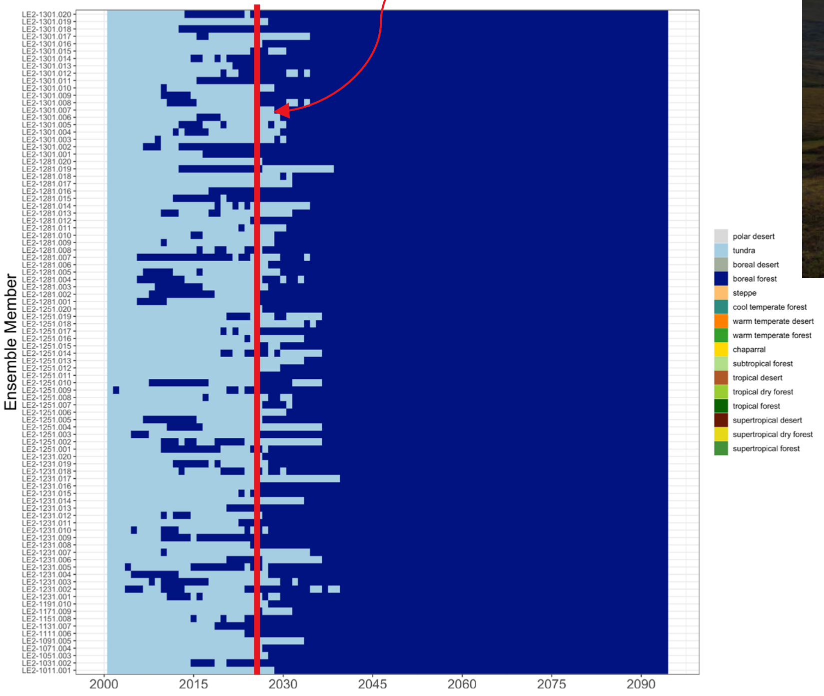
White spruce tree in the tundra;
Roman Dial



Timing of biome shifts

Toolik Lake, AK

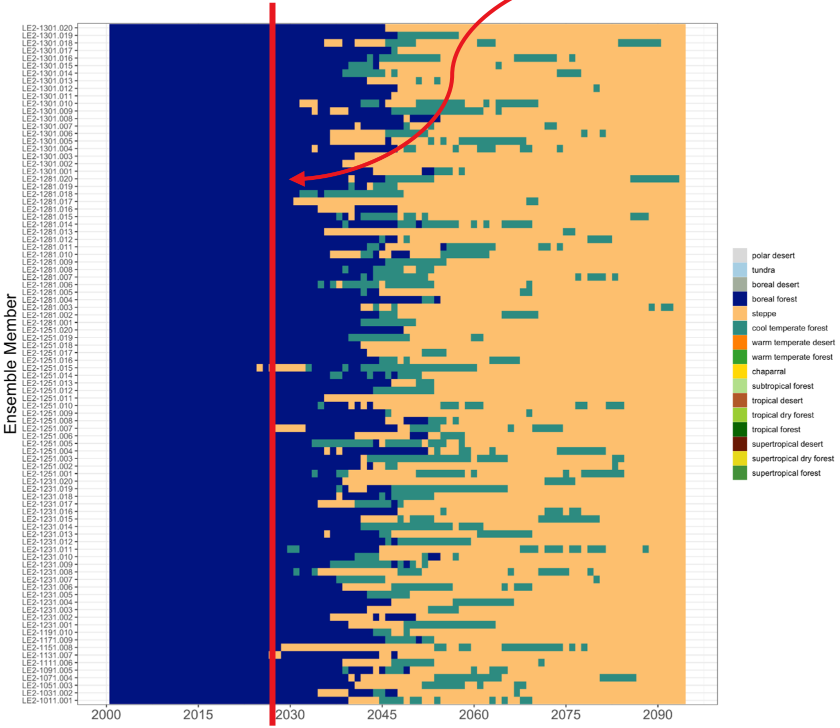
You are here



Timing of biome shifts

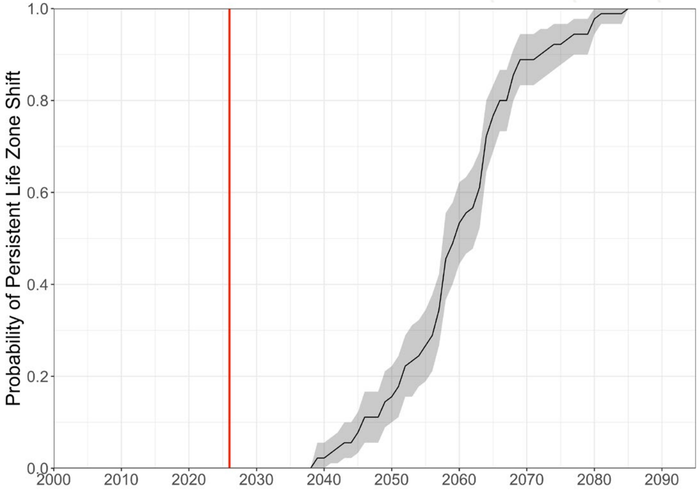
central Canada

You are here

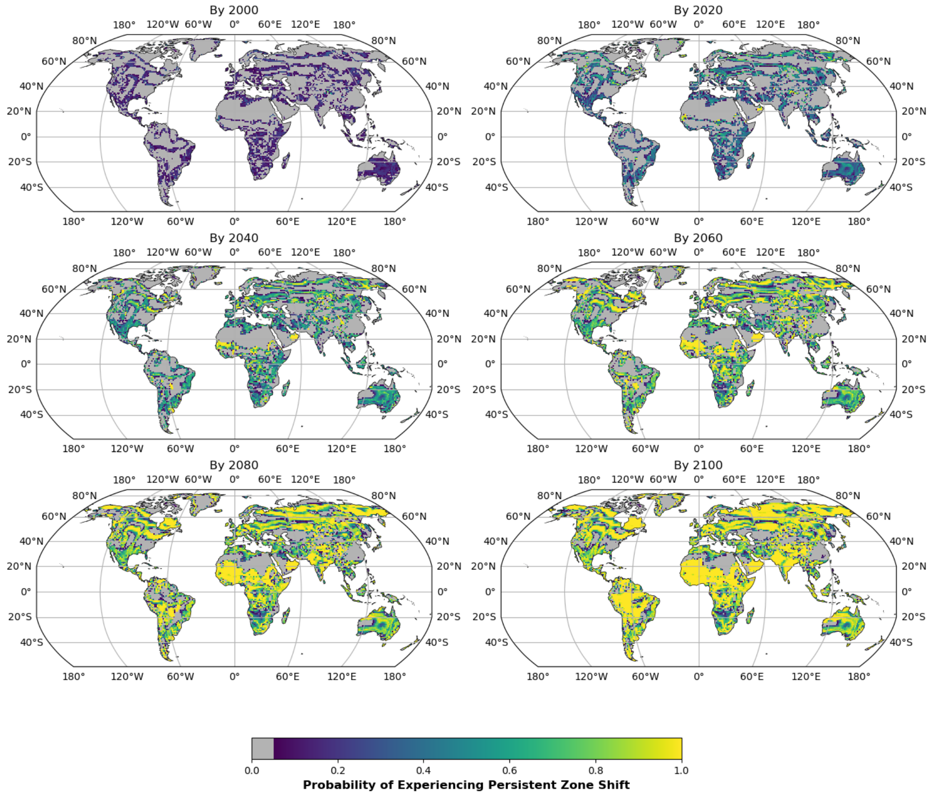


HOLDRIDGE LIFE ZONES

Boreal browning near Dunvegan, Alberta; *Devin Letourneau*



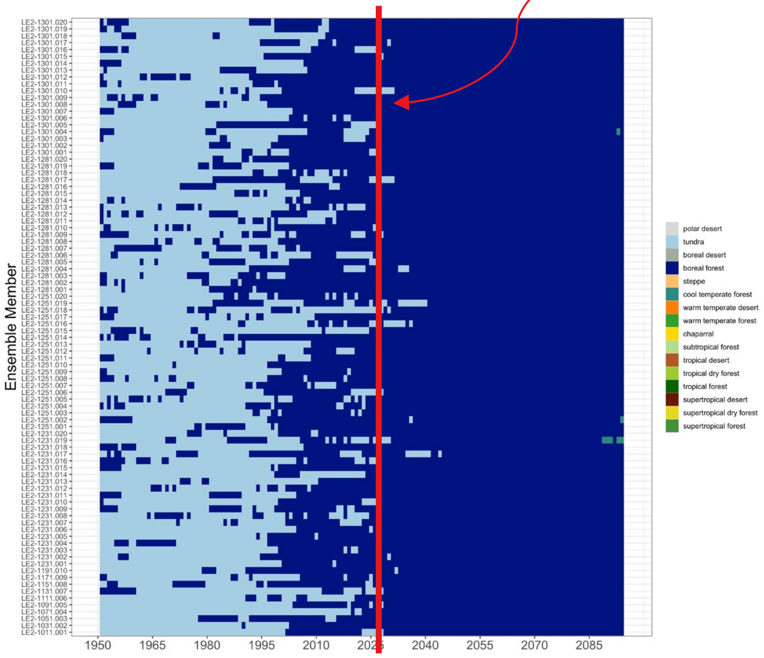
Timing of biome shifts



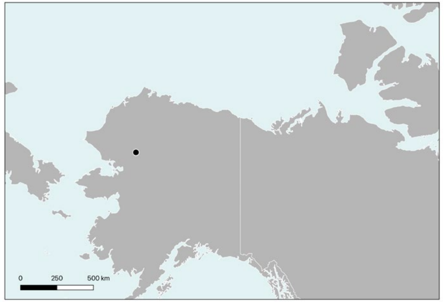
Timing of biome shifts

Brooks Range, AK

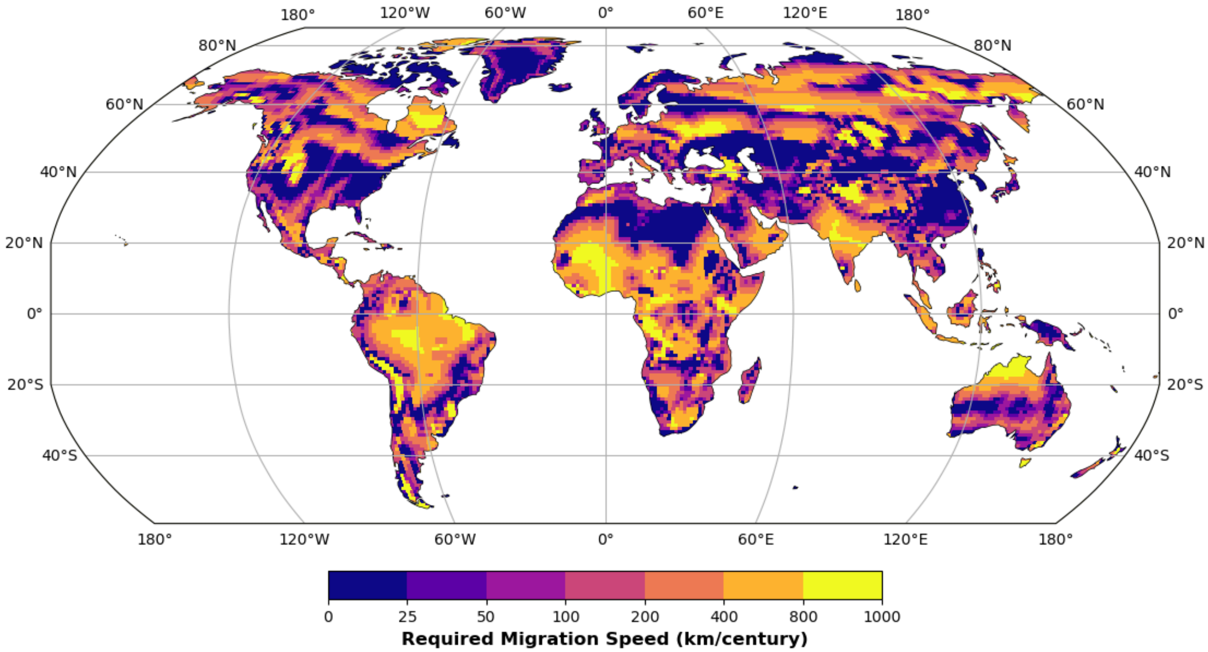
You are here

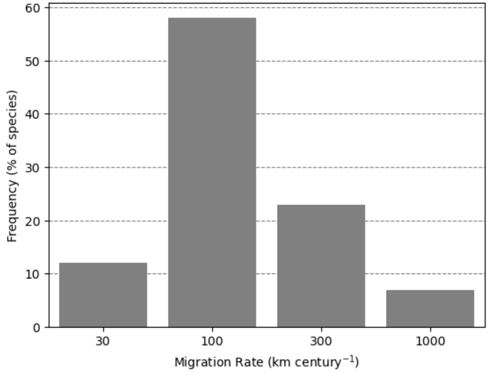


White spruce tree in the tundra; *Roman Dial*



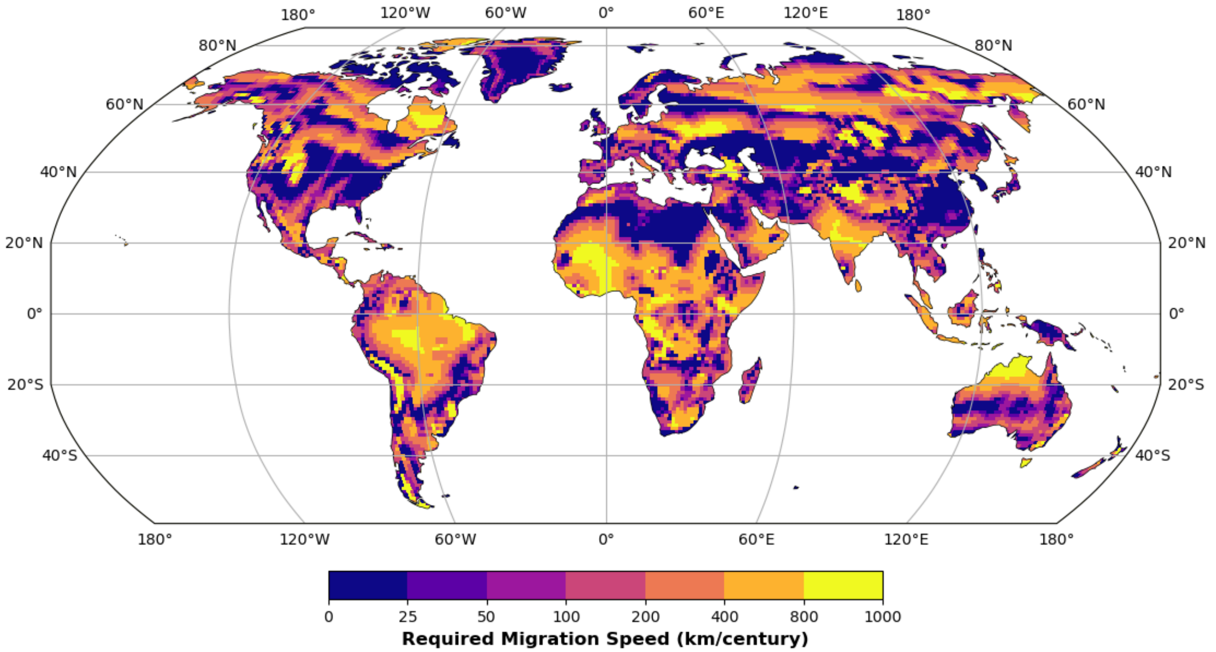
Required species migration





MacDonald 1993

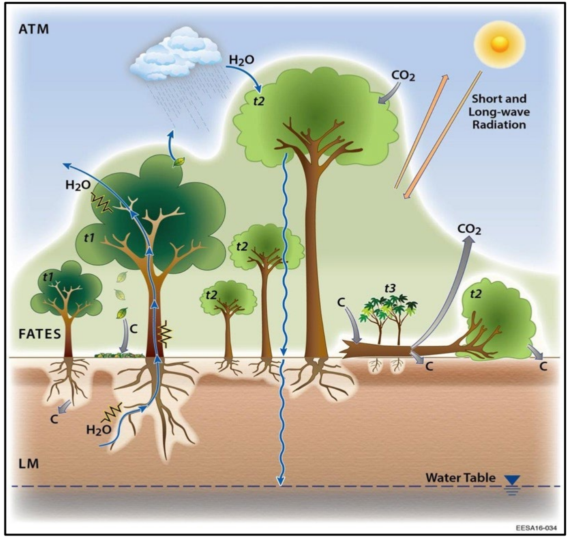
Required species migration



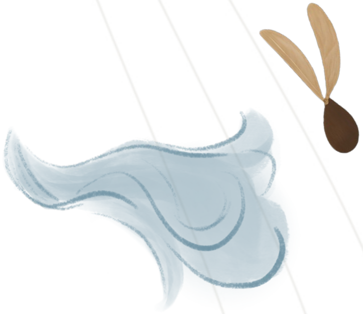
Required species migration

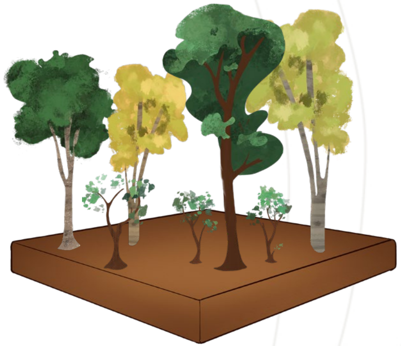
Earth system models need to model vegetation shifts prognostically

- ➢ Competition, climate feedbacks, etc.



FATES





Conclusions

1. Climate space is predicted to shift rapidly across the CESM ensemble
2. Change is happening now
3. Many ecosystems are projected to require migration rates far above what most species historically have achieved
4. Timing of shifts is uncertain

Thank you!

Questions?