

Retreat and Regrowth of the Greenland Ice Sheet During the Last Interglacial as Simulated by the CESM2-CISM2 Coupled Climate Ice Sheet Model

*Aleah Sommers, Bette Otto-Bliesner, William Lipscomb, Marcus Lofverstrom, Sarah Shafer, Patrick Bartlein,
Esther Brady, Erik Kluzek, Gunter Leguy, Katherine Thayer-Calder, Robert Tomas*



February 5, 2021
CESM Land Ice/Paleoclimate Working Group Meeting

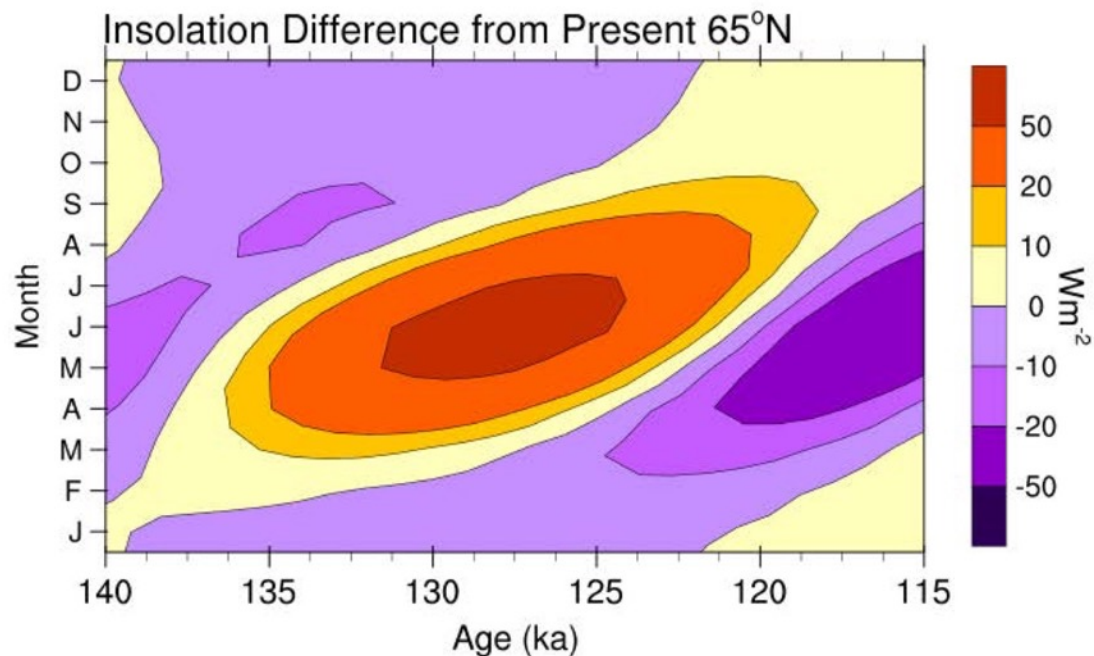


Last Interglacial, LIG, Eemian, MIS 5e

~129,000 – 116,000 years ago

Warmer than present climate, primarily due to:

- Changes in solar insolation from orbital configuration (high summer anomaly in northern hemisphere)

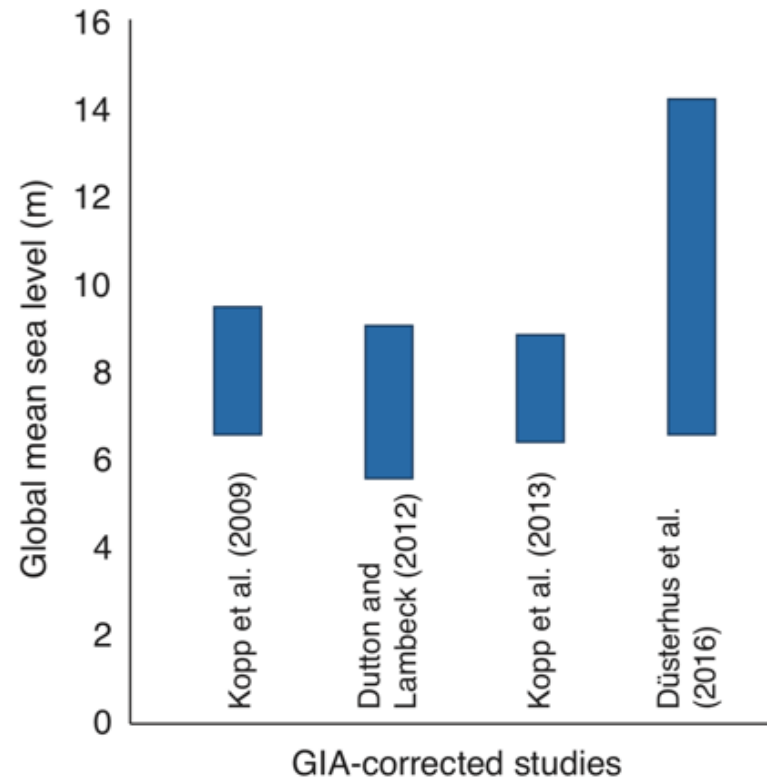


- Changes in albedo (vegetation distribution)

→ Arctic summer temperatures 3-5 degrees C warmer than present

Why are we interested in the Last Interglacial?

- To learn about important behavior and feedbacks under warming conditions that may be relevant for the future
- Sea level high-stand during the LIG was likely ~6-9 m higher than present



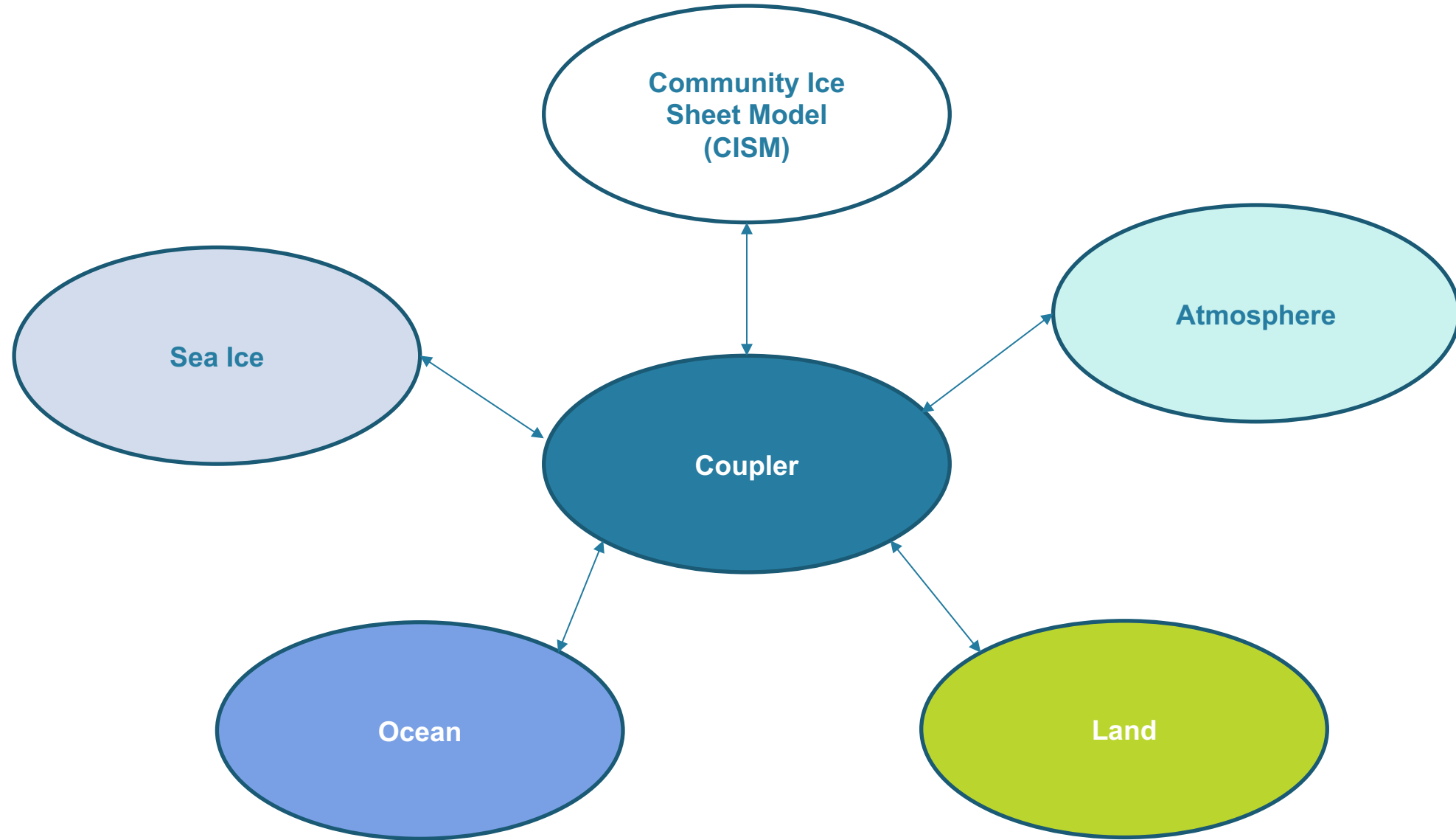
How much of that sea level rise was due to contributions from Greenland?

- Summary by Dutton et al. (2015): **2.0 m (+/- 1.5 m)**
- Yau et al. (2016): **5.1 m (+/- 1 m)**

Goal:

Conduct a transient, fully coupled global climate simulation with a dynamic Greenland ice sheet during the Last Interglacial

Community Earth System Model, CESM 2.1

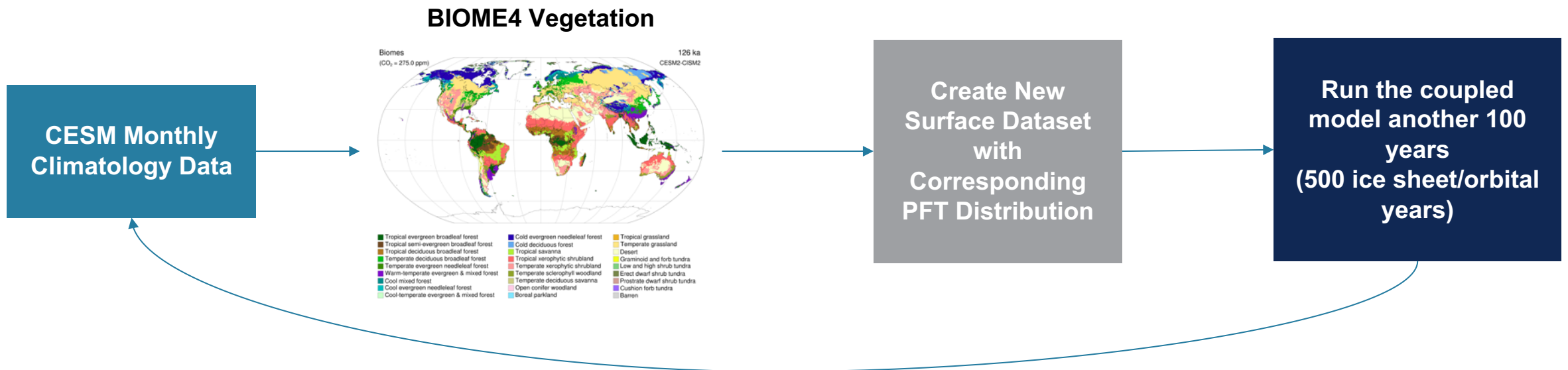


Transient LIG Run Design

- 127-119 ka (8,000 years)
- 5x acceleration of ice sheet (total of 1,600 fully coupled CESM years)
- 5x acceleration of orbital parameters
- Vegetation changed every 500 years based on BIOME4 modeled vegetation

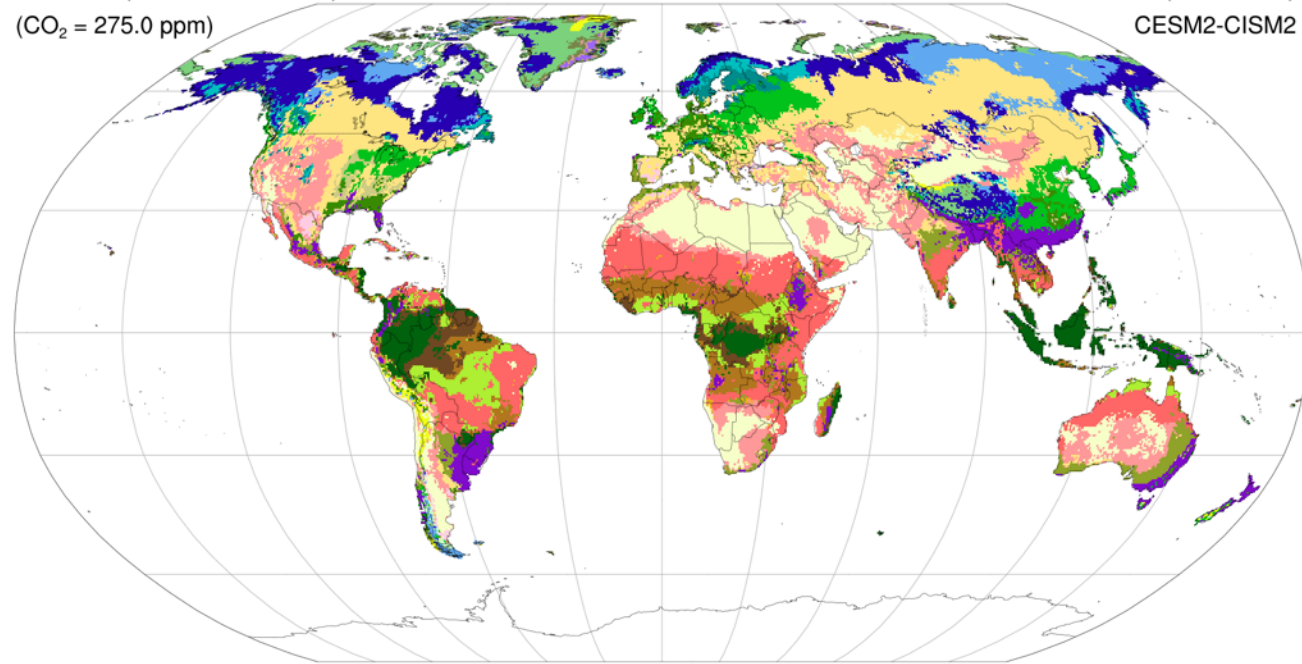
Transient LIG Run Design

- 127-119 ka (8,000 years)
- 5x acceleration of ice sheet (total of 1,600 fully coupled CESM years)
- 5x acceleration of orbital parameters
- Vegetation changed every 500 years based on BIOME4 modeled vegetation



Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

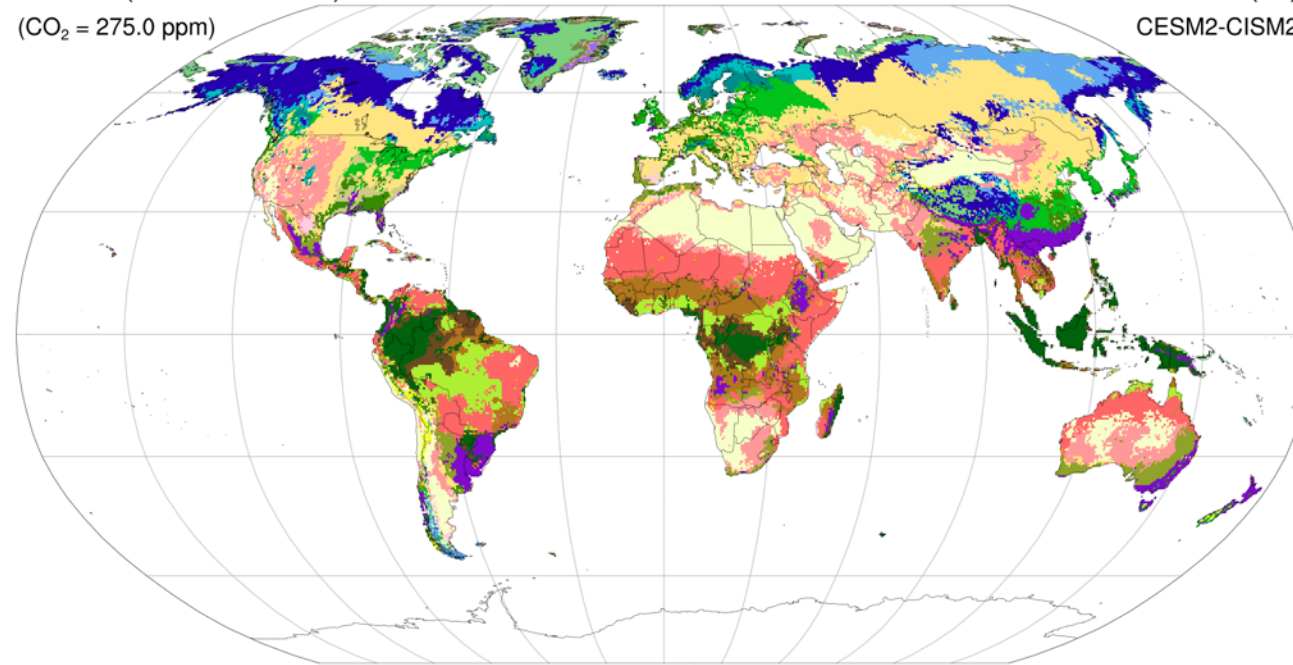
126.0 ka (redo test)
CESM2-CISM2



- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

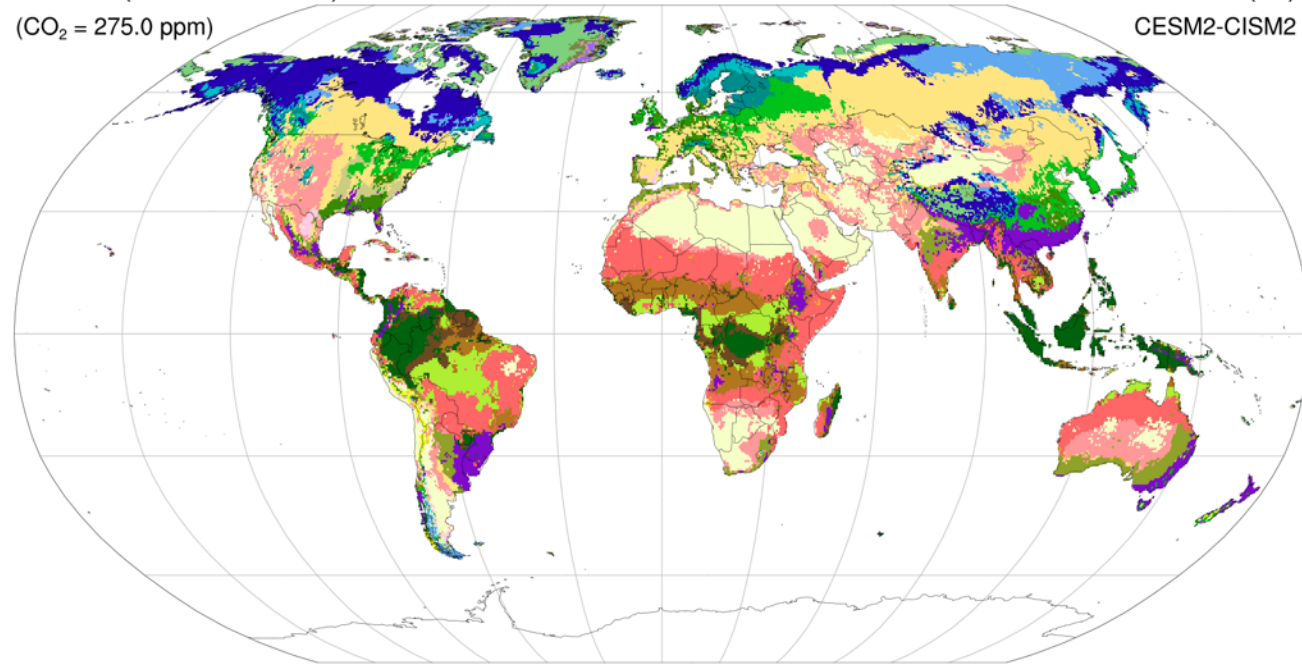
125.5 ka (v2)
CESM2-CISM2



- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

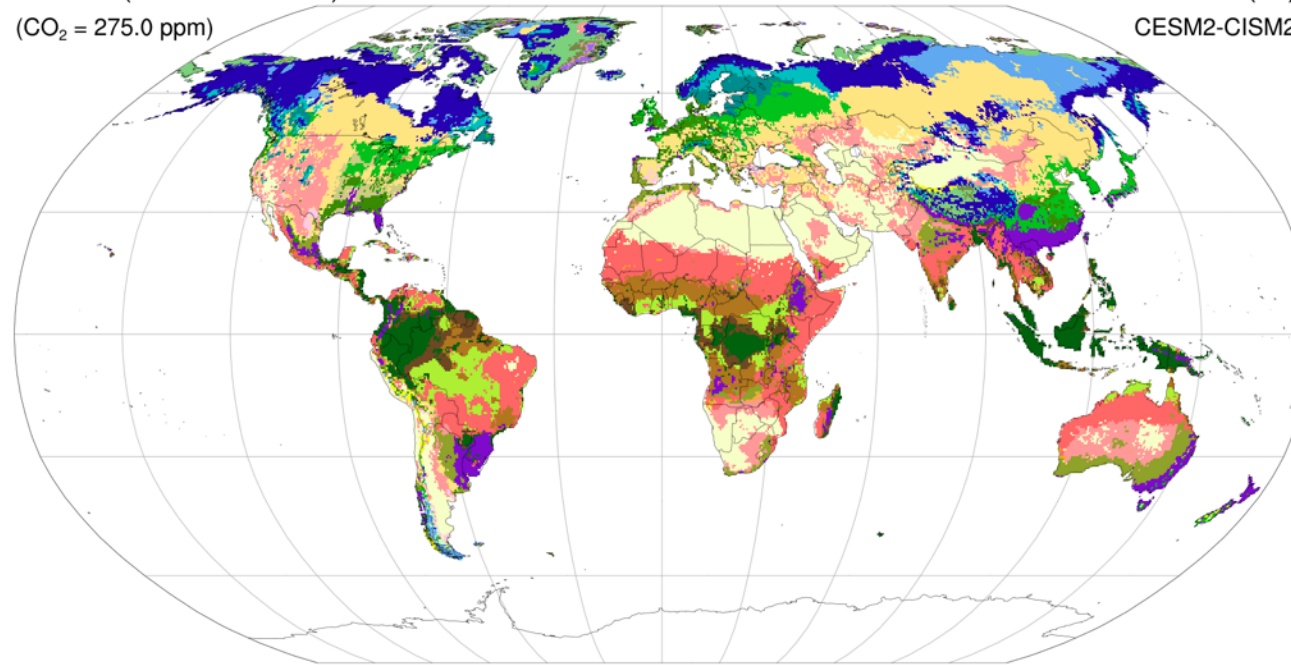
125.0 ka (v2)
CESM2-CISM2



- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

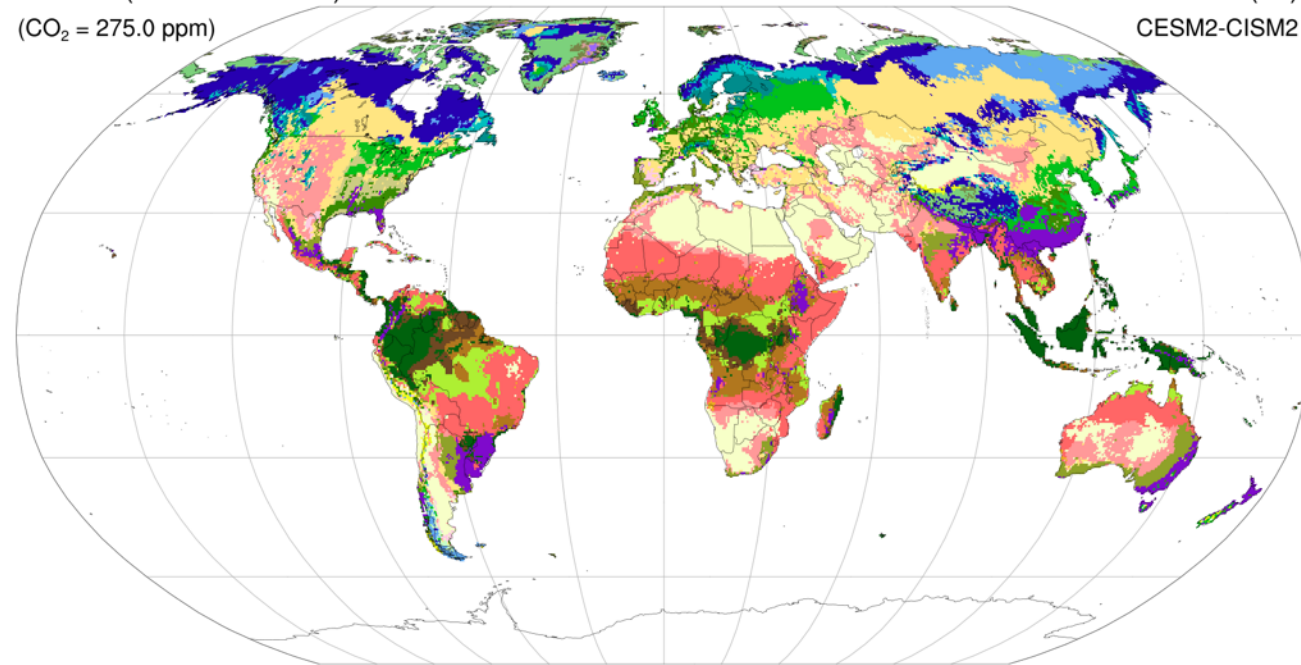
124.5 ka (v2)
CESM2-CISM2



- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

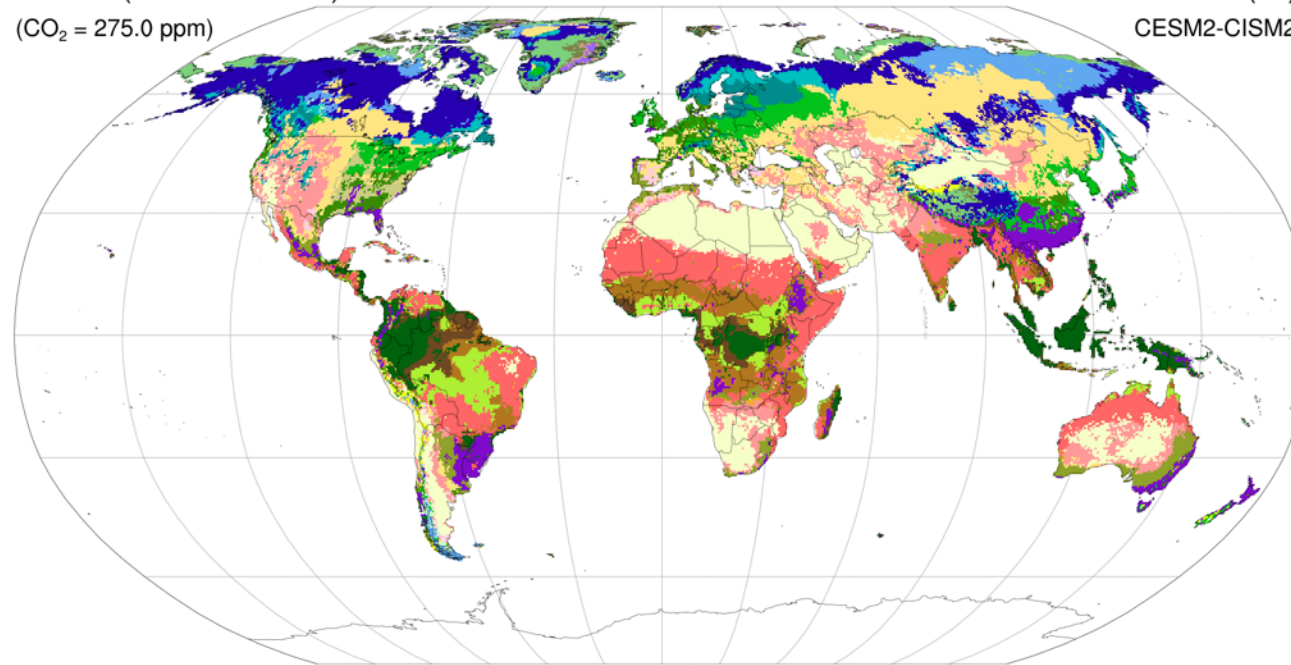
124.0 ka (v2)
CESM2-CISM2



- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

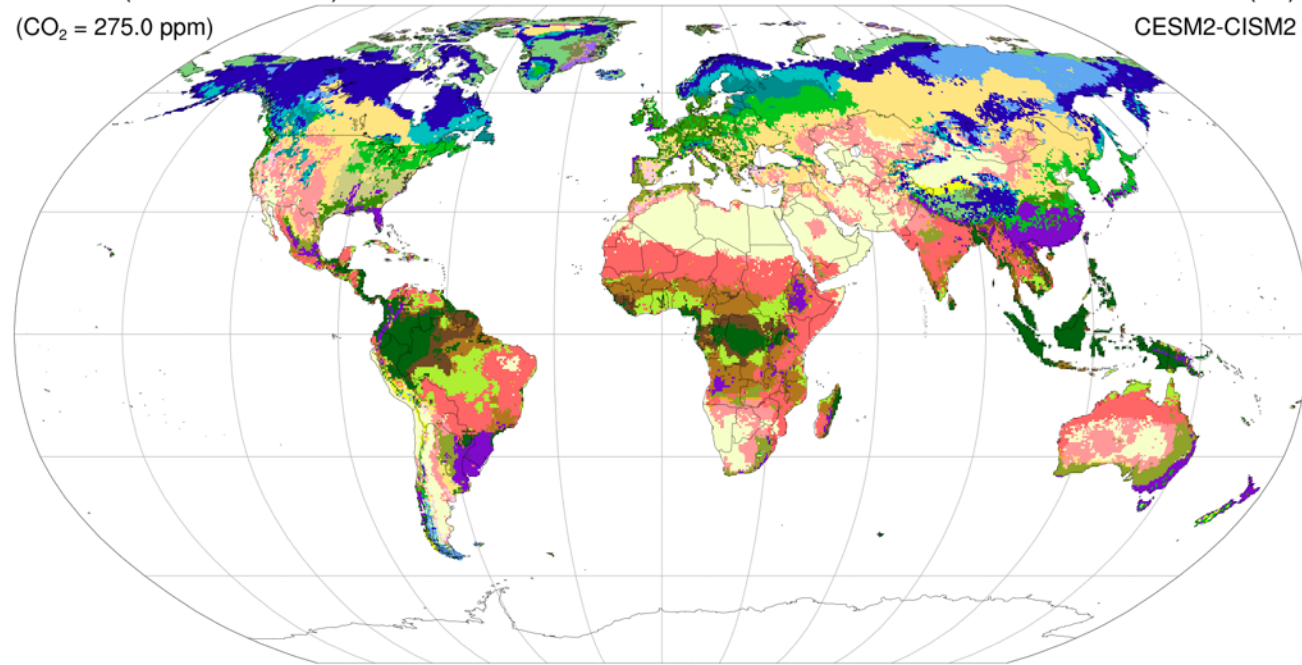
123.5 ka (v2)
CESM2-CISM2



- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

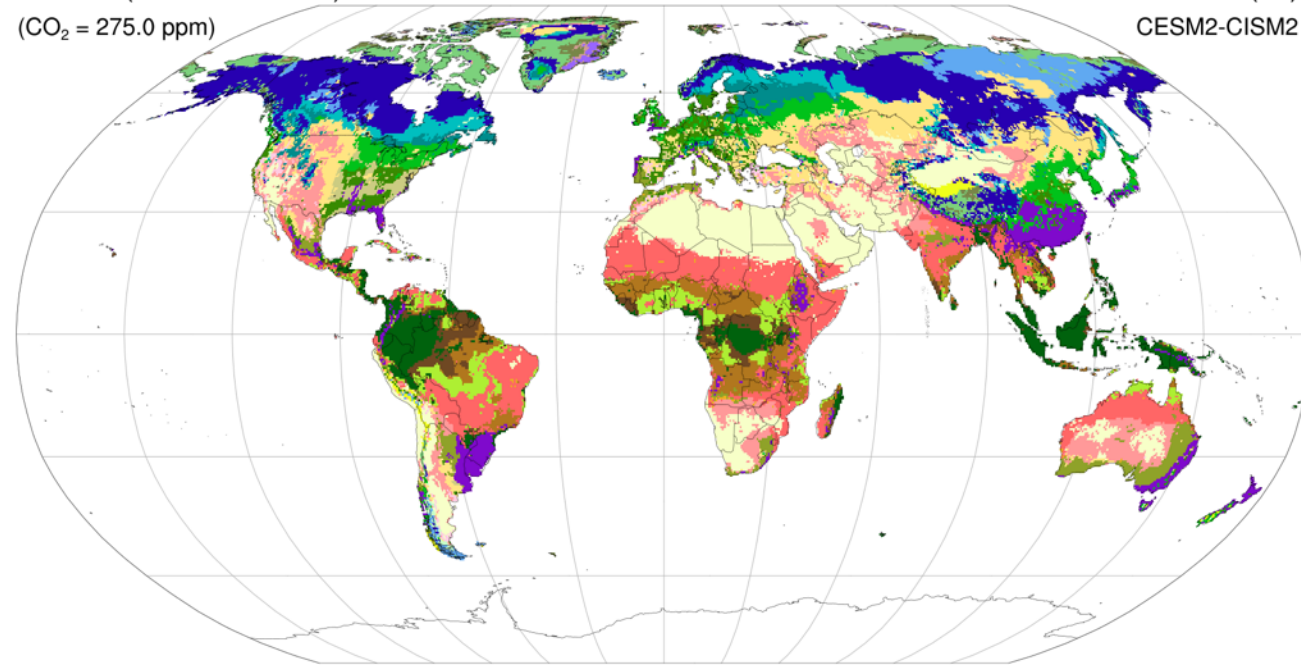
122.5 ka (v2)
CESM2-CISM2



- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

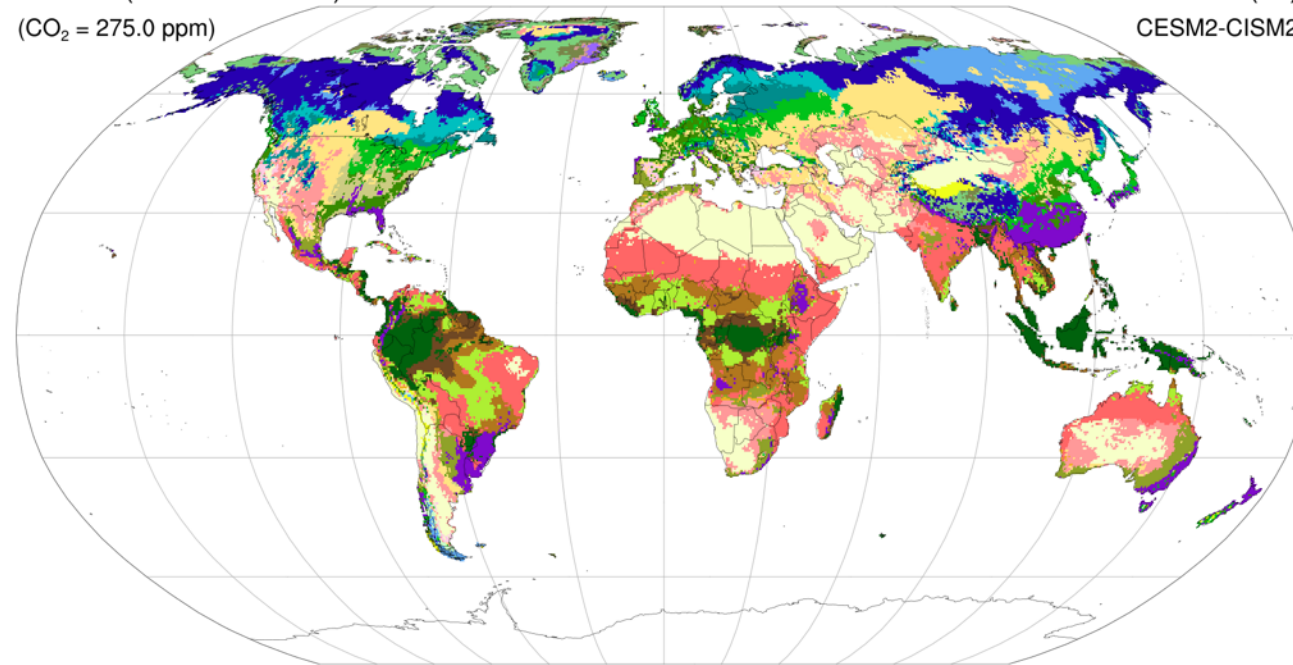
122.0 ka (v2)
CESM2-CISM2



- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

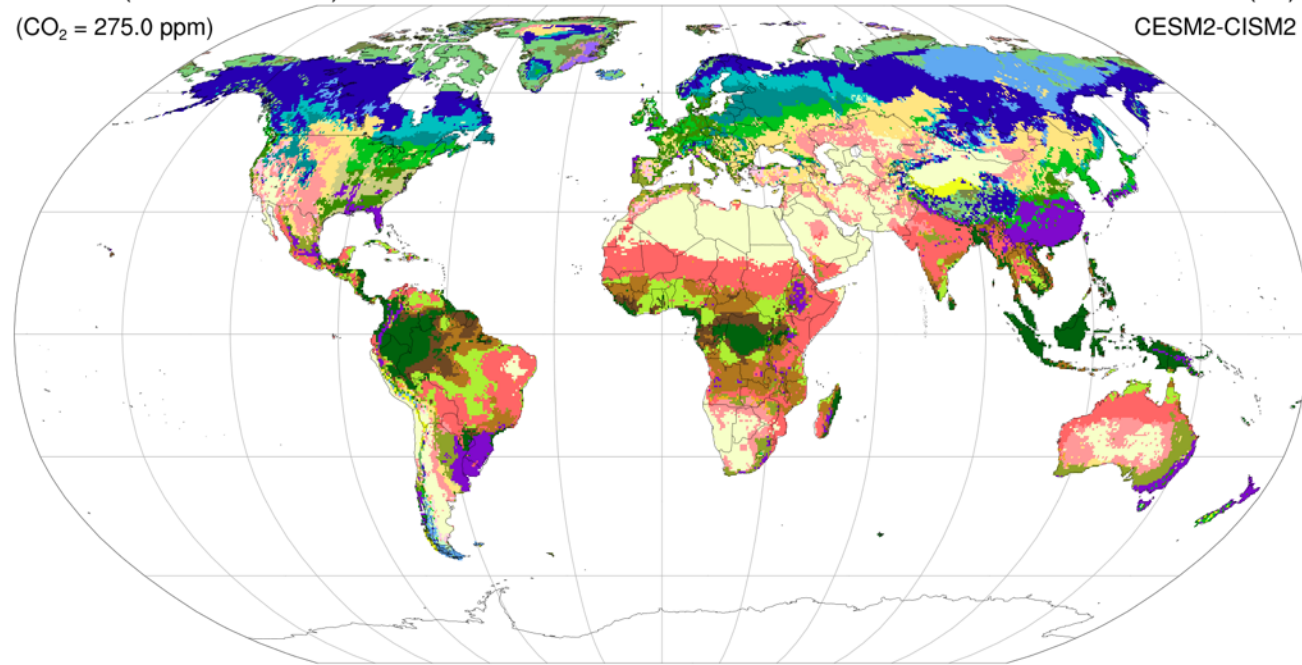
121.5 ka (v2)
CESM2-CISM2



- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

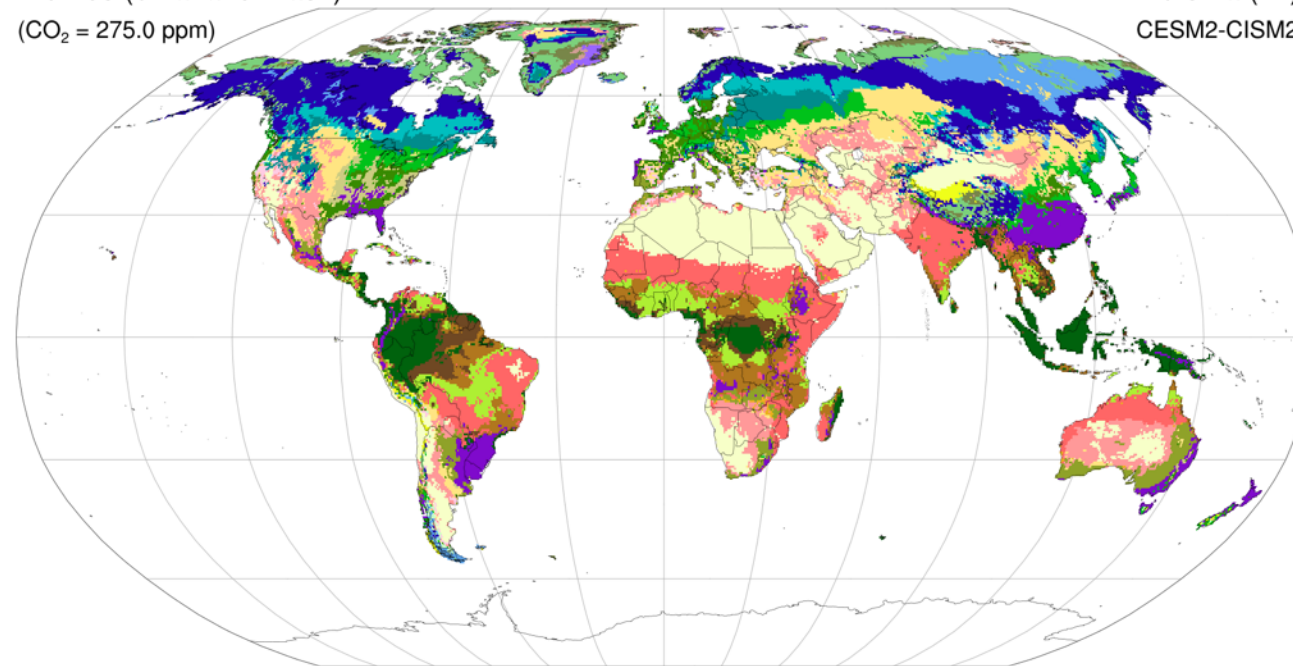
121.0 ka (v2)
CESM2-CISM2



- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

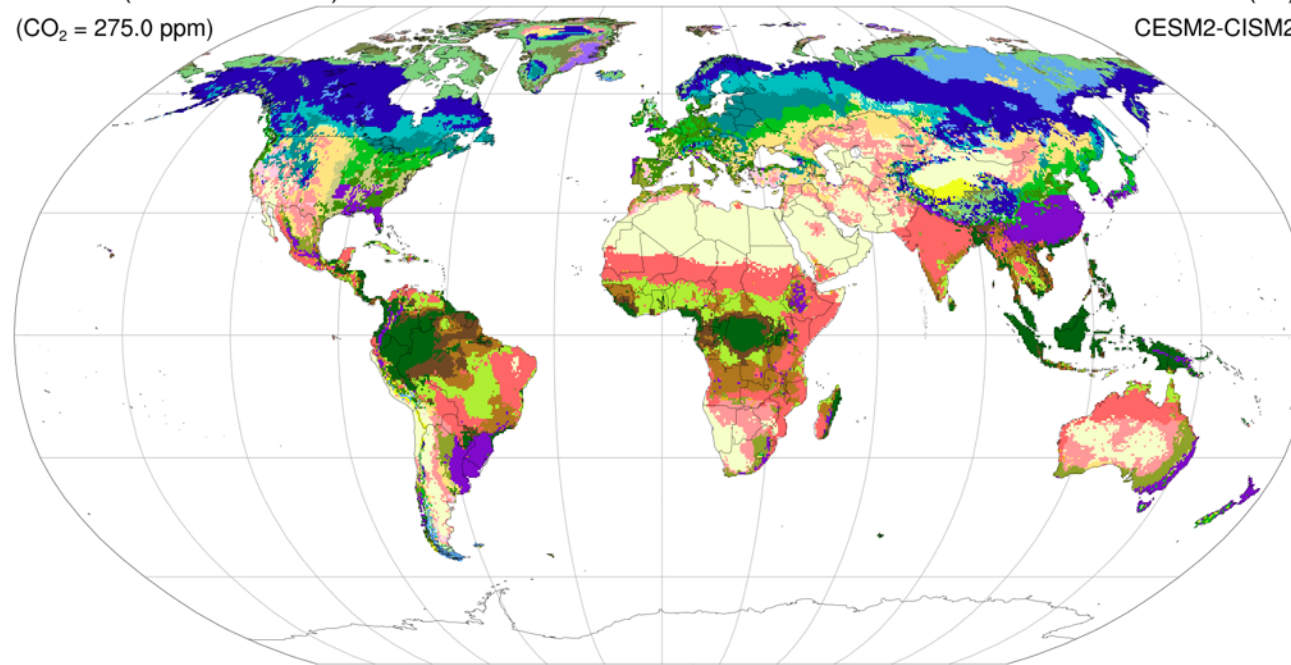
120.5 ka (v2)
CESM2-CISM2



- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

Biomes (0 ka land mask)
(CO₂ = 275.0 ppm)

120.0 ka (v2)
CESM2-CISM2

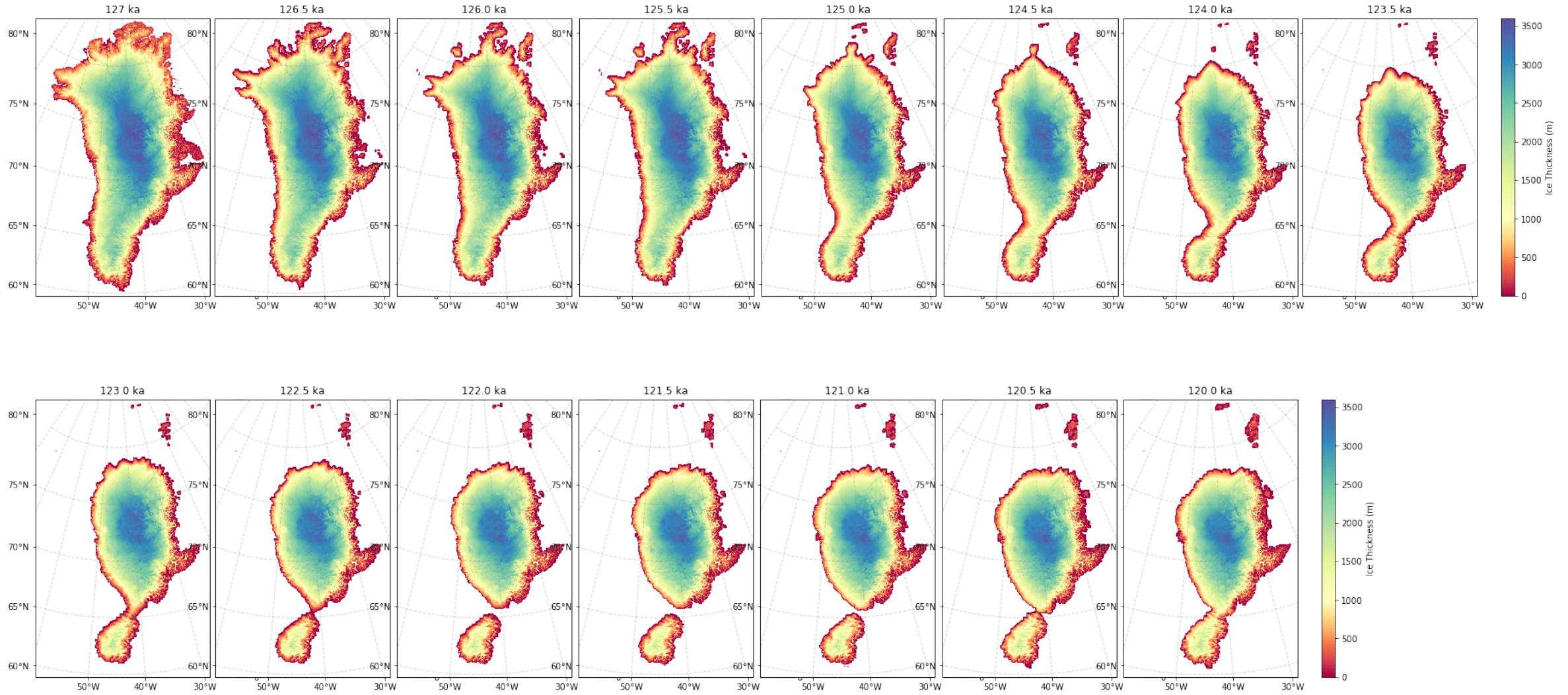


- | | | |
|--|------------------------------------|--------------------------------|
| ■ Tropical evergreen broadleaf forest | ■ Cold evergreen needleleaf forest | ■ Tropical grassland |
| ■ Tropical semi-evergreen broadleaf forest | ■ Cold deciduous forest | ■ Temperate grassland |
| ■ Tropical deciduous broadleaf forest | ■ Tropical savanna | ■ Desert |
| ■ Temperate deciduous broadleaf forest | ■ Tropical xerophytic shrubland | ■ Graminoid and forb tundra |
| ■ Temperate evergreen needleleaf forest | ■ Temperate xerophytic shrubland | ■ Low and high shrub tundra |
| ■ Warm-temperate evergreen & mixed forest | ■ Temperate sclerophyll woodland | ■ Erect dwarf shrub tundra |
| ■ Cool mixed forest | ■ Temperate deciduous savanna | ■ Prostrate dwarf shrub tundra |
| ■ Cool evergreen needleleaf forest | ■ Open conifer woodland | ■ Cushion forb tundra |
| ■ Cool-temperate evergreen & mixed forest | ■ Boreal parkland | ■ Barren |

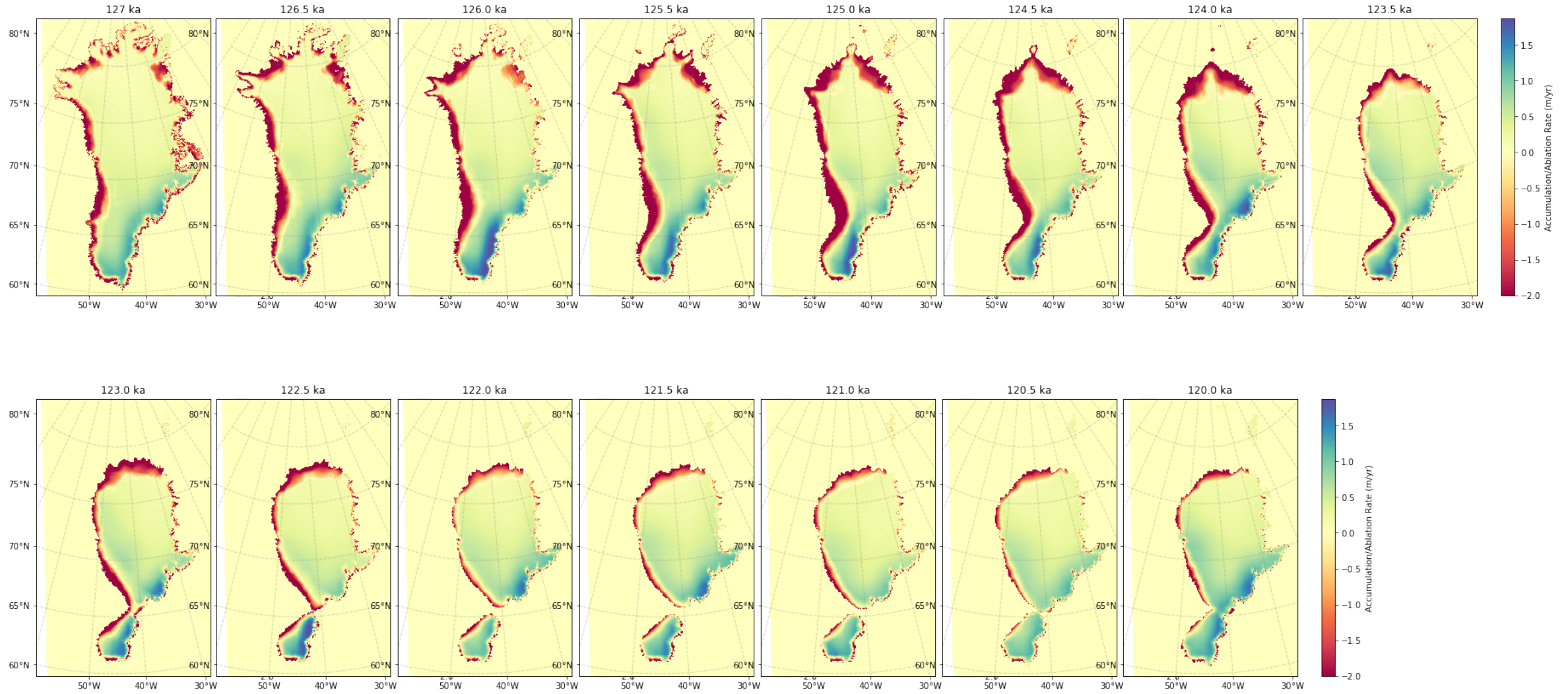
Results

127-120 ka
(7,000 years)

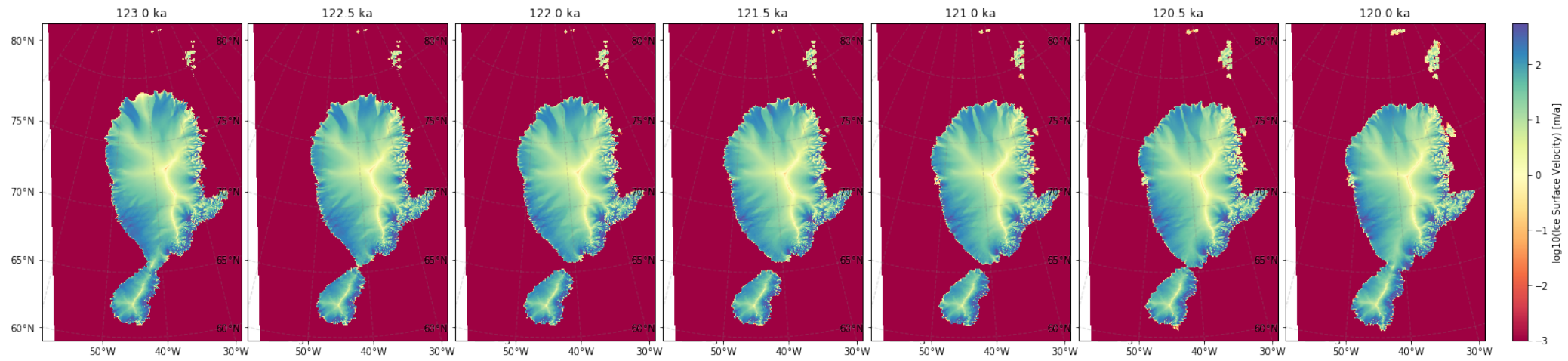
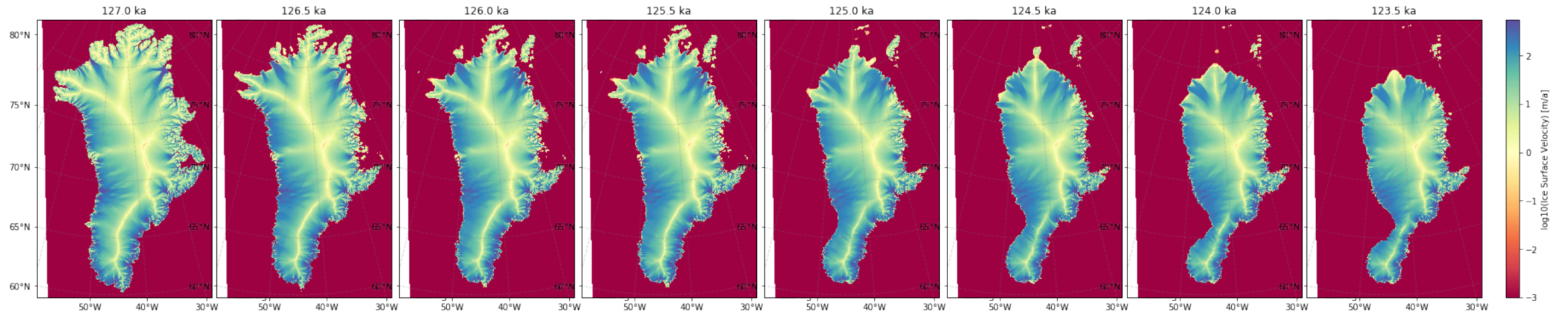
Ice Thickness



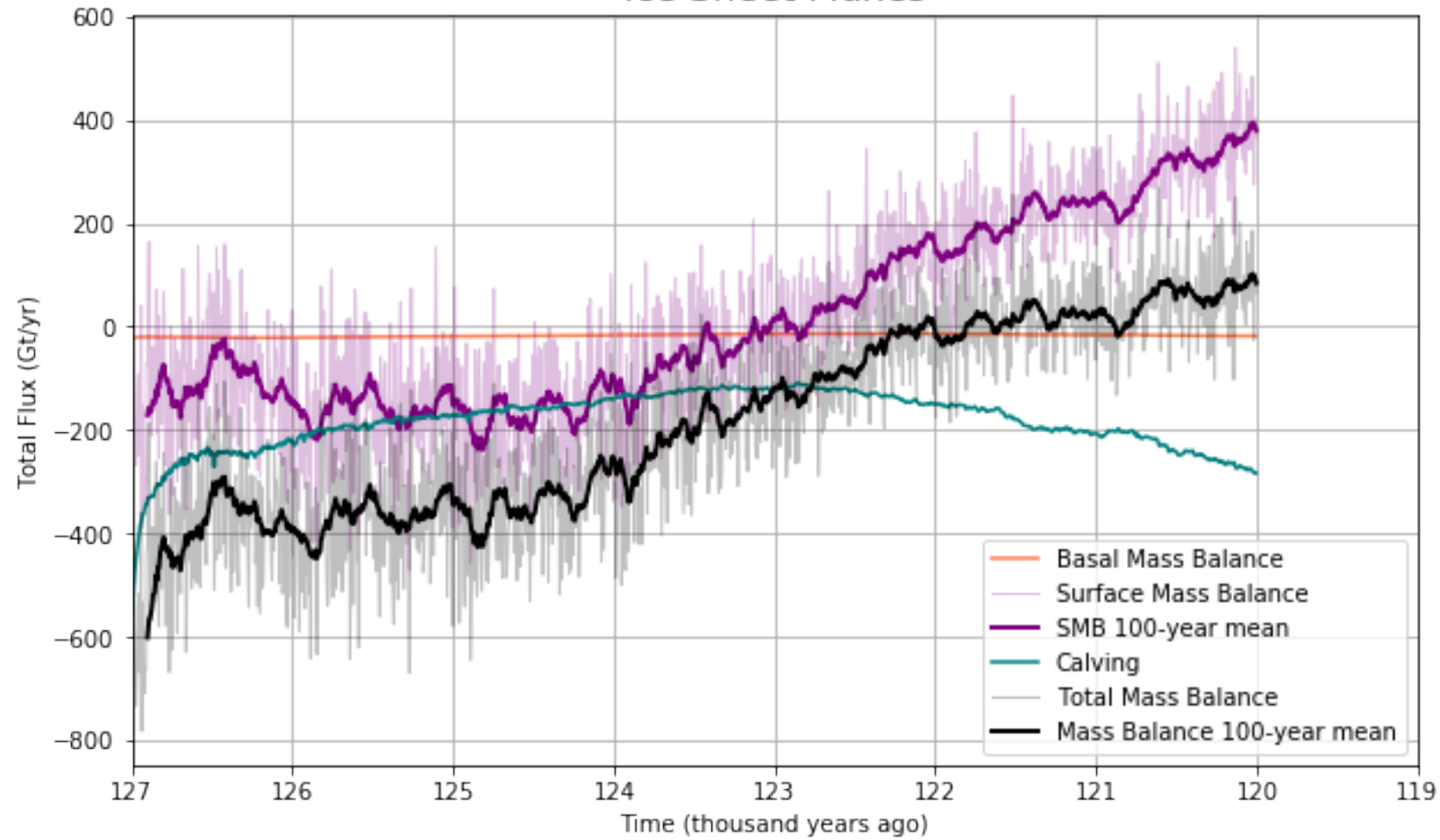
Accumulation/Ablation



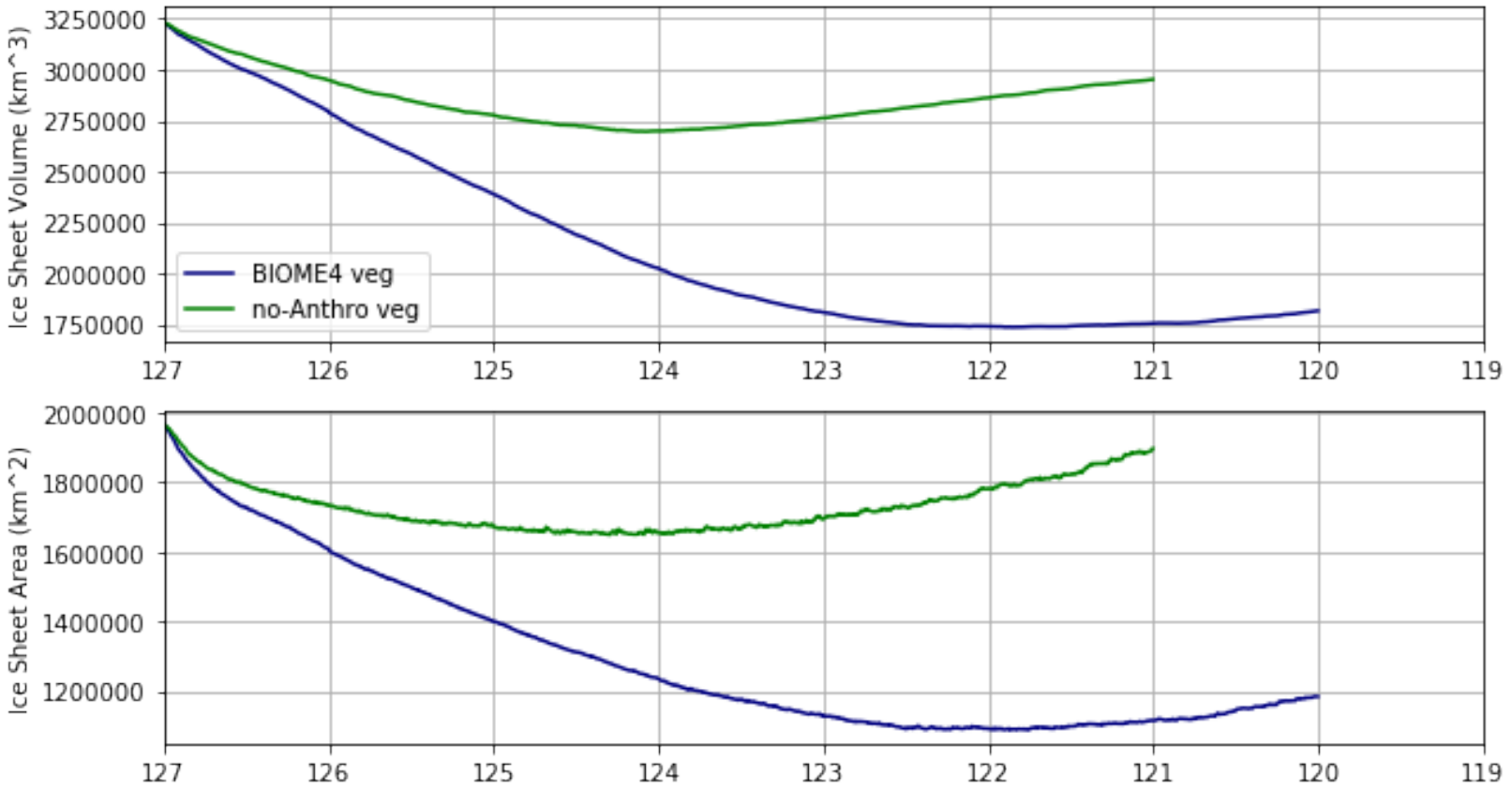
Surface Velocity



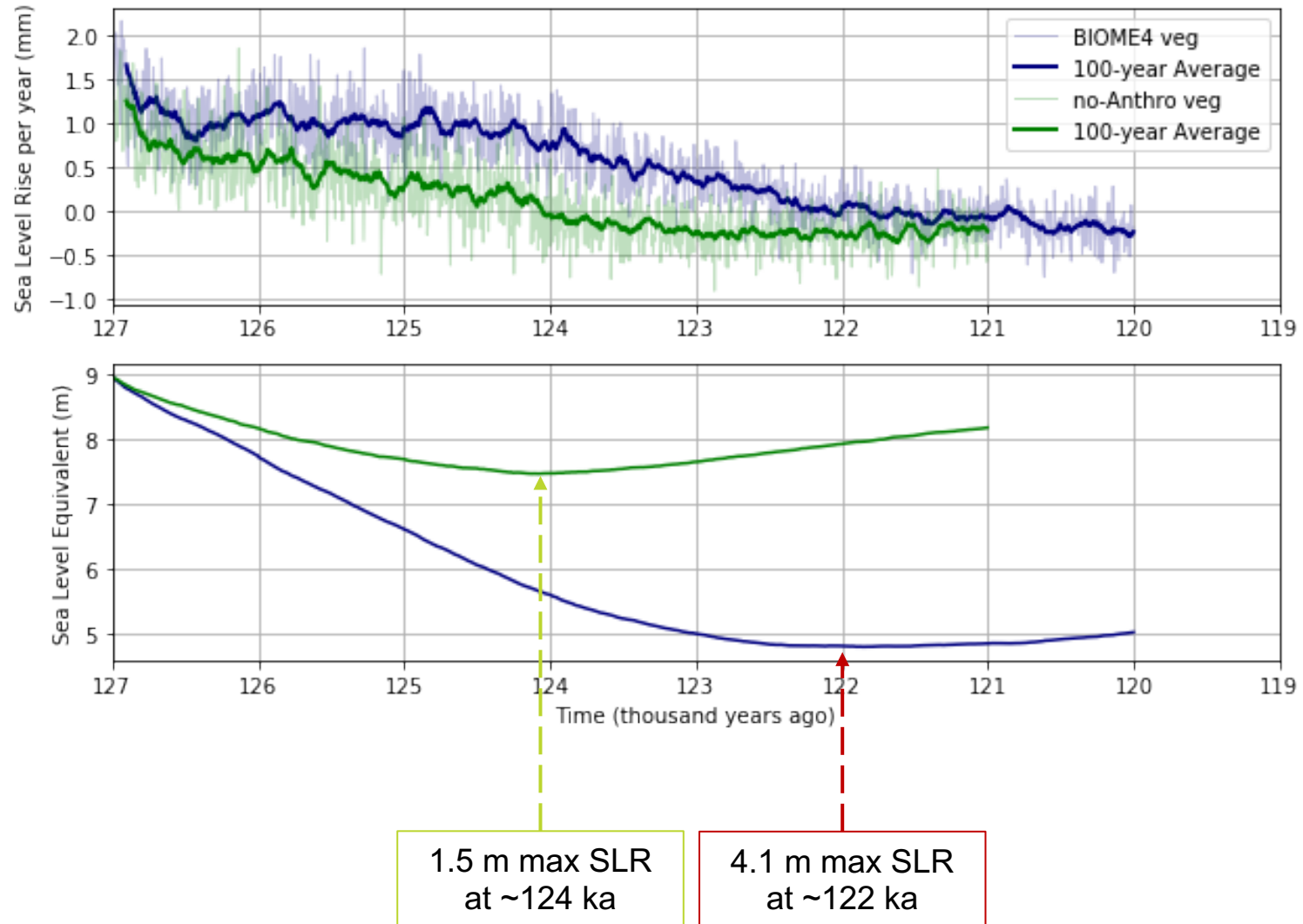
Ice Sheet Fluxes



Ice Sheet Volume and Area



Sea Level Contribution



Findings

- This fully coupled global climate/ice sheet simulation presents a new estimate of the timing and magnitude of Greenland ice sheet retreat during the Last Interglacial
 - Global vegetation distribution plays an important role in climate interactions and ice sheet evolution
- Impacts on ocean, atmosphere, sea ice, etc.? Much model output and data available for analysis! Many stories to tell...

Thank you.



Contact: [aleahsommers @ gmail.com](mailto:aleahsommers@gmail.com)