Climate Speeds Help Frame Ecological Risk in Future Climate Change and Stratospheric Aerosol Injection Scenarios

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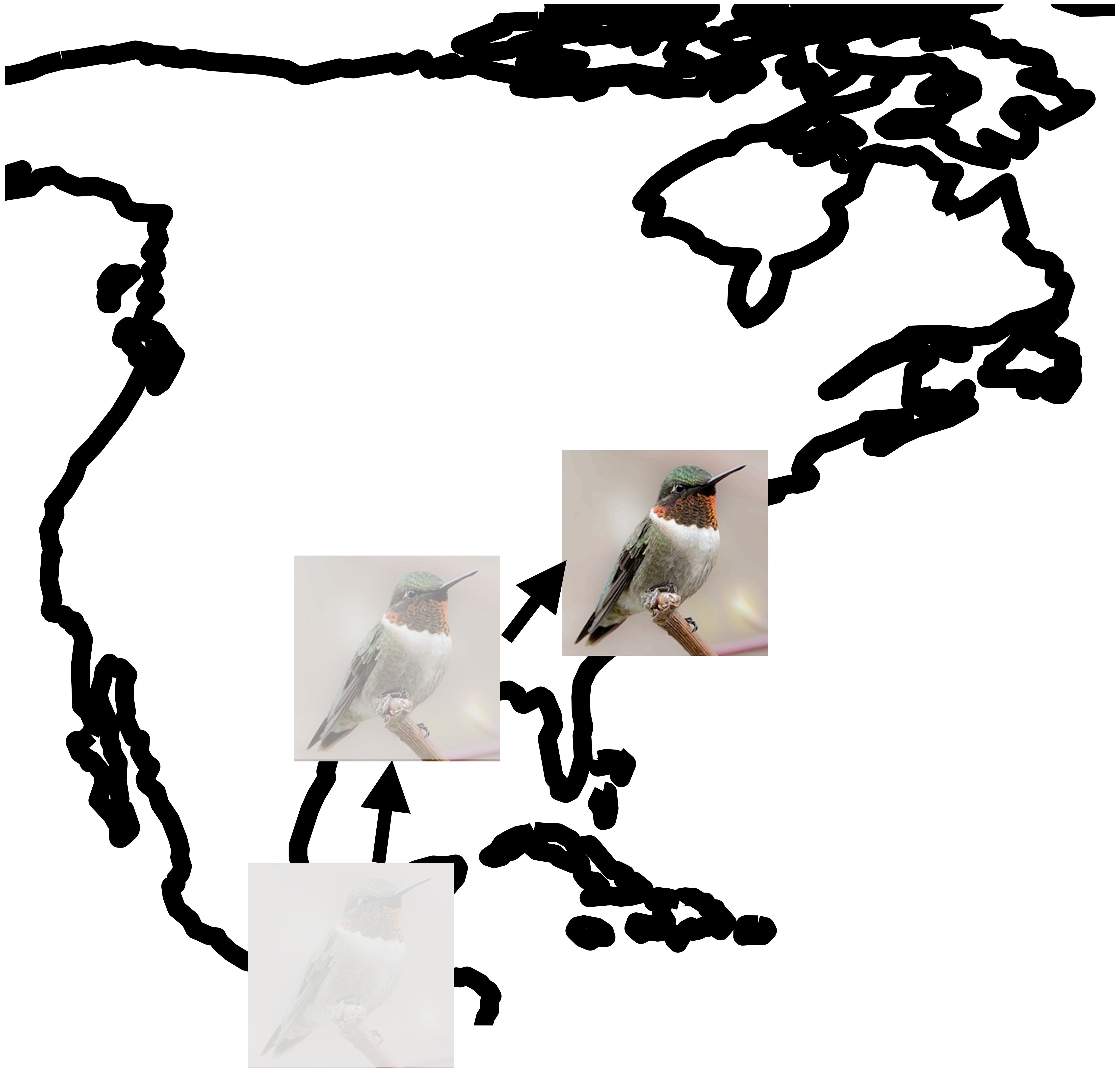
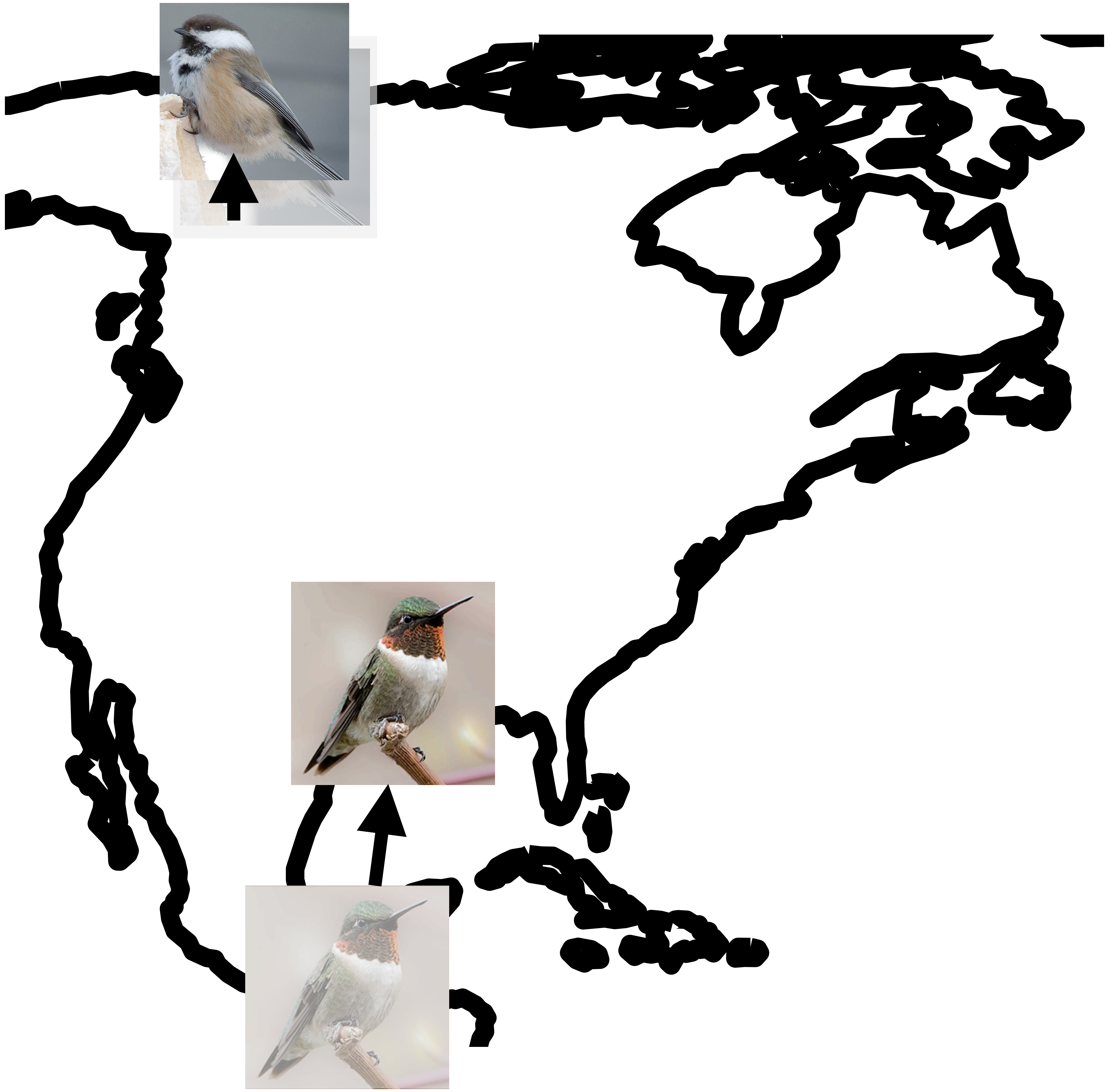
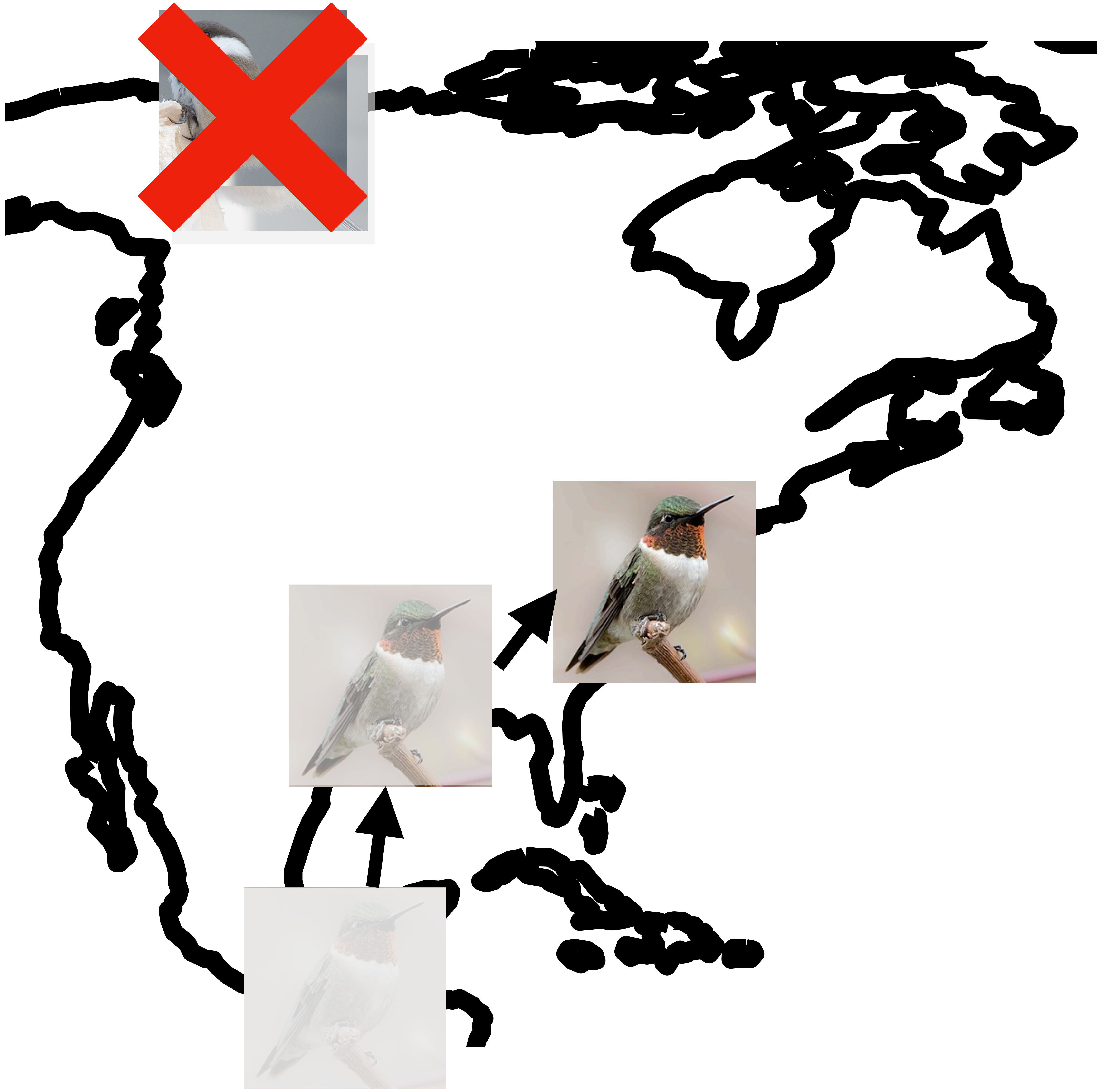
In general, species want to stay in the thermal niche to which they are acclimated

Climate change redistributes ecosystems if they can respond quickly enough

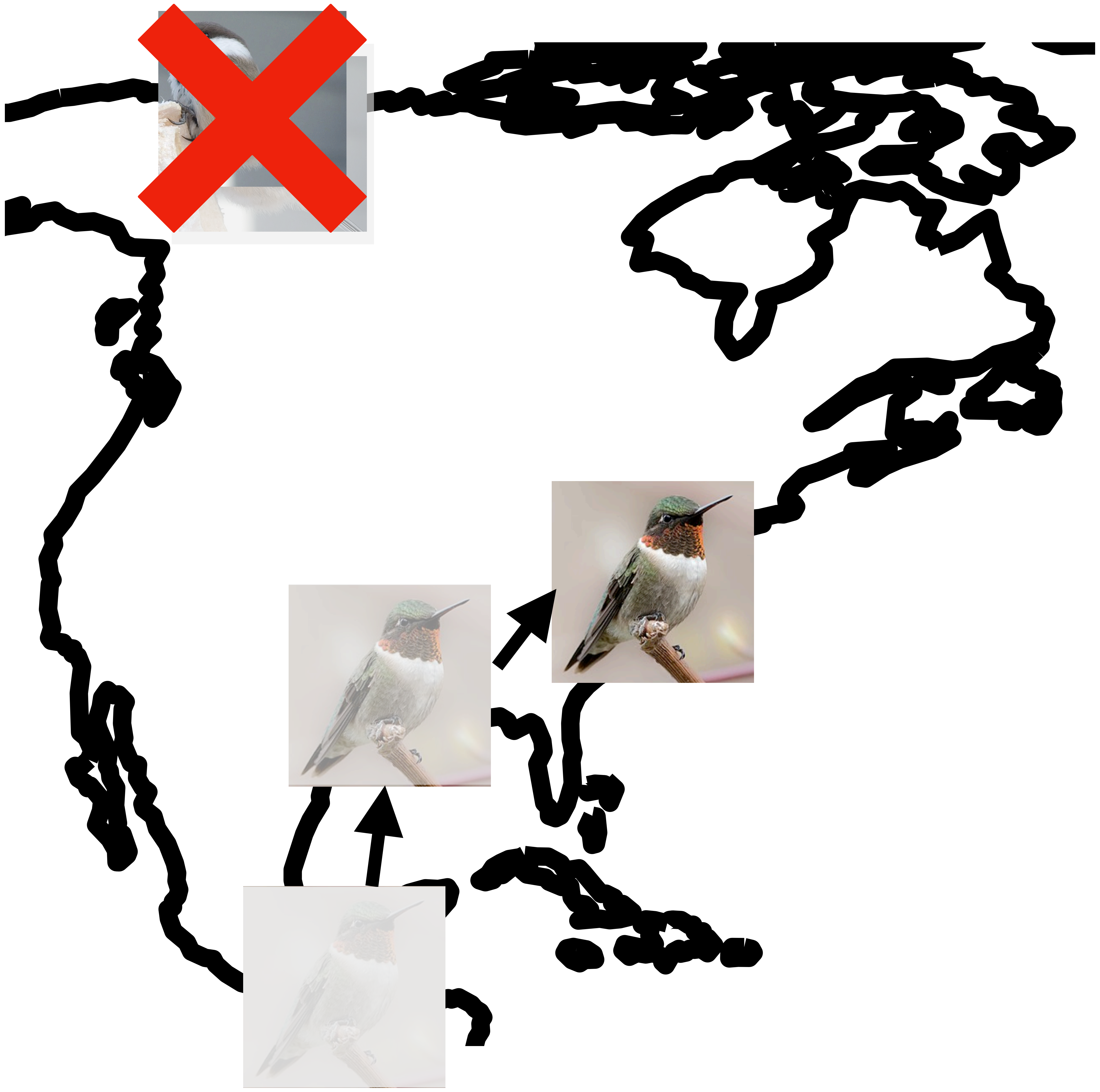


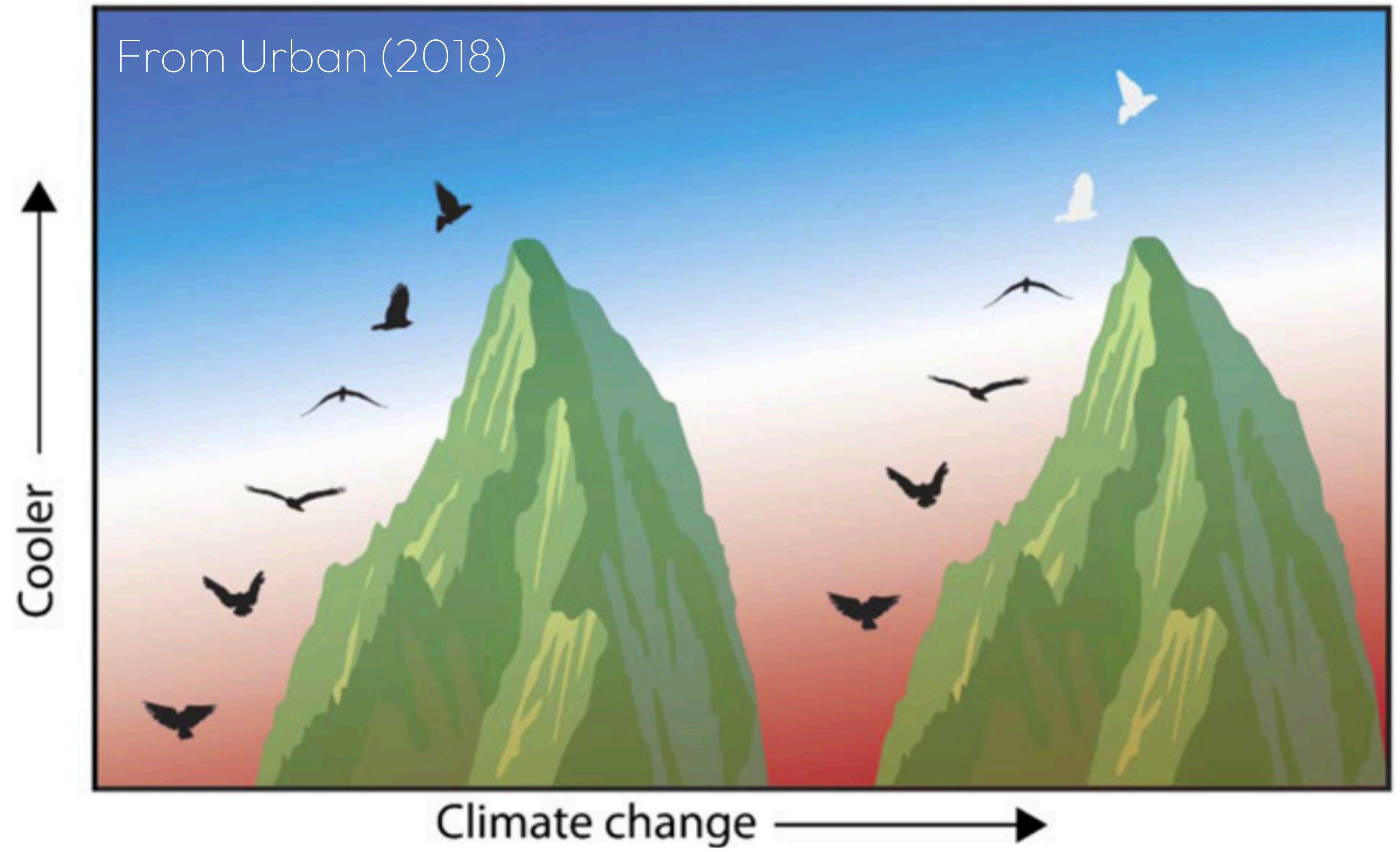


Climate change endangers ecosystems around transport barriers or when rates of change are fast



A similar process occurs around topography





The movement of thermal niches in a changing climate poses risks for a wide range of terrestrial and marine species

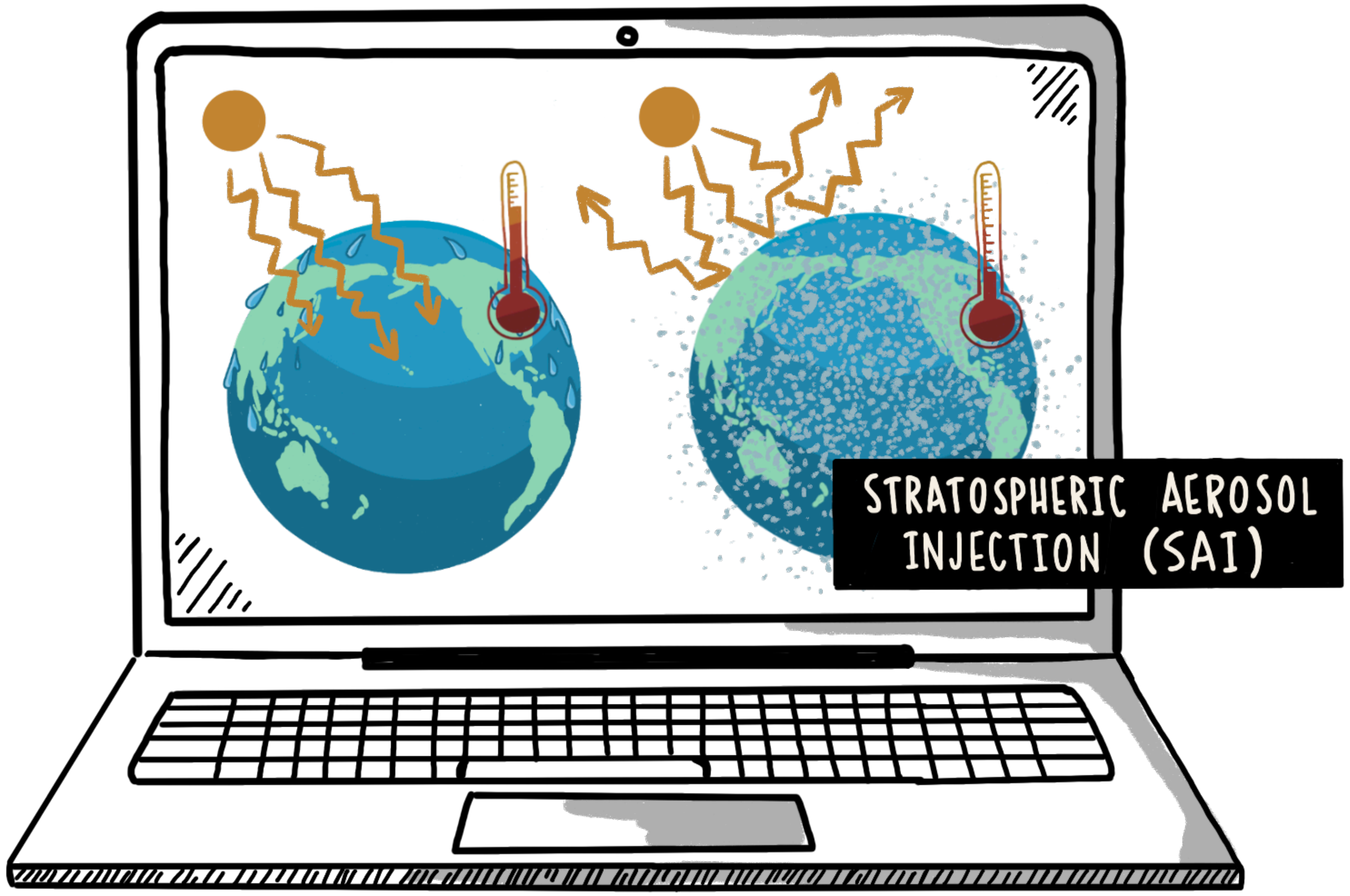
- **Climate velocity of 2m temperature:** the rate of movement needed to stay in the starting isotherm[1]
- Speeds >1-2 km/yr (land) or >7 km/yr (ocean) are a problem; >10 km/yr are a **big** problem (anywhere)[1-6]
- Most suited for linear change on timescale $\geq$10 yrs[7]
- Climate speeds already affect ecosystems globally, and are expected to redistribute and endanger species under all Shared Socioeconomic Pathways[7-9]

$$\frac{\frac{^\circ C}{\text{time}}}{\frac{^\circ C}{\text{space}}} = \frac{\text{space}}{\text{time}} \text{ (e.g., km/yr)}$$

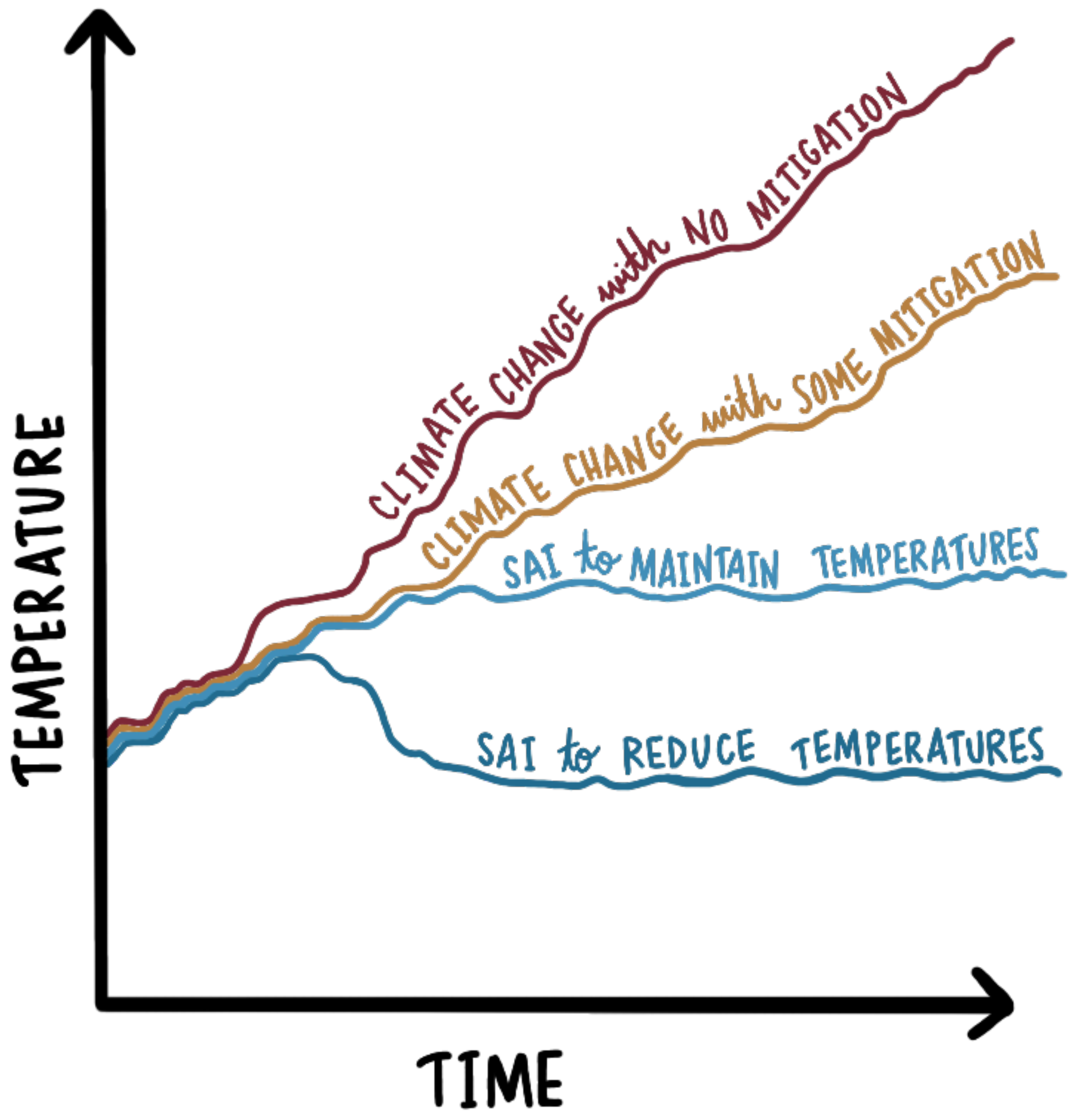
Yields a vector ("climate velocity"); we analyze the magnitude ("climate speed")

Worsening climate risks motivates research into climate intervention

- Stratospheric aerosol injection (SAI) is a hypothetical approach to reduce global temperature by emitting reflective particles into the upper atmosphere[10]
- Analogous to processes that occur naturally after large volcanic eruptions[10]
- **SAI is not a substitute for decarbonization**—but could complement its goals[10,11]



How might SAI complement decarbonization?



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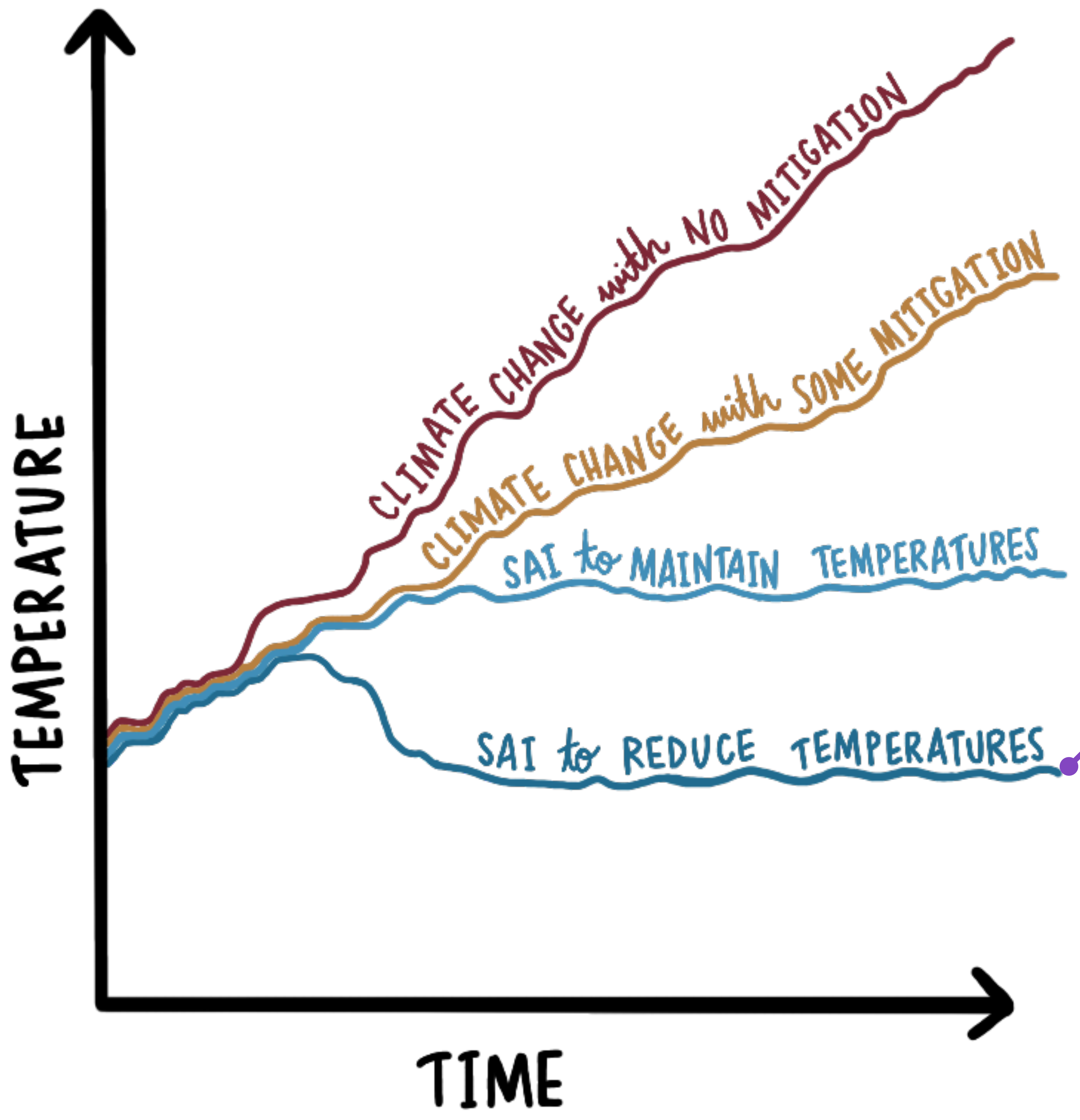
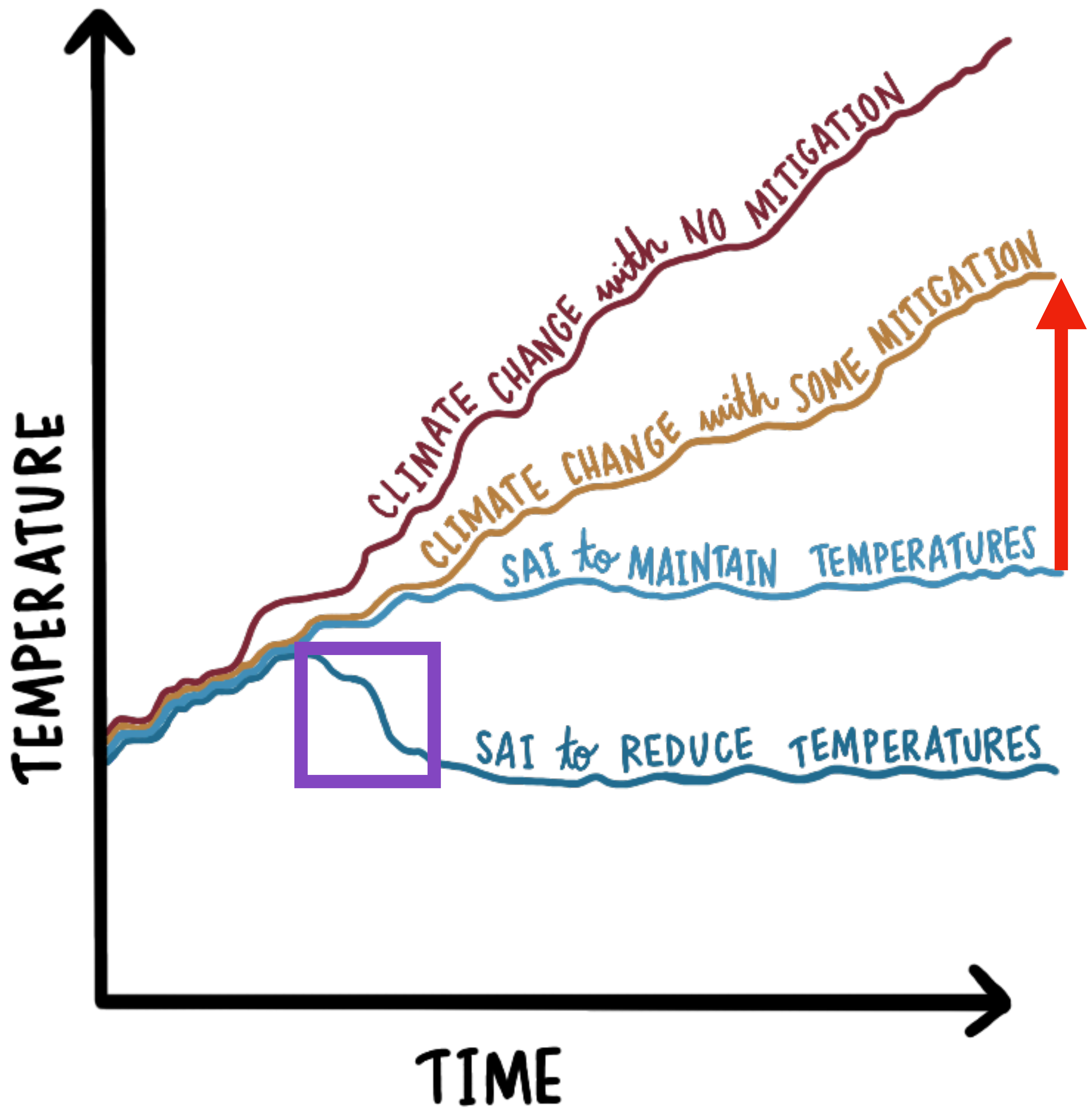


"An operational SRM deployment is the only known approach that could be deliberately implemented to cool the Earth within a few years [...] if global warming at some point produces outcomes widely seen as intolerable [...] **an operational SRM deployment as part of a 'planned' emergency response might be able to alleviate some of this suffering within a few years"**

-UNEP (2023)

How does this fit into the climate speed (rate of change) framework?



- **SAI adds an additional potential dimension of rapid change at the deployment or termination of an intervention**
- Previous work has emphasized the termination piece ("termination shock")[2,12,13]
- Question: **What specific strategic design choices lead to harmful climate speeds following deployment?**

Assessing Responses and Impacts of Solar climate intervention on the Earth system with stratospheric aerosol injection (ARISE-SAI)[14,15]

SSP2-4.5
Moderate mitigation of greenhouse gas emissions with slow deployment of negative emissions technologies [10 members]

ARISE-1.5
Starting in 2035, *maintain* global mean temperature at ~1.5˚C
[10 members]

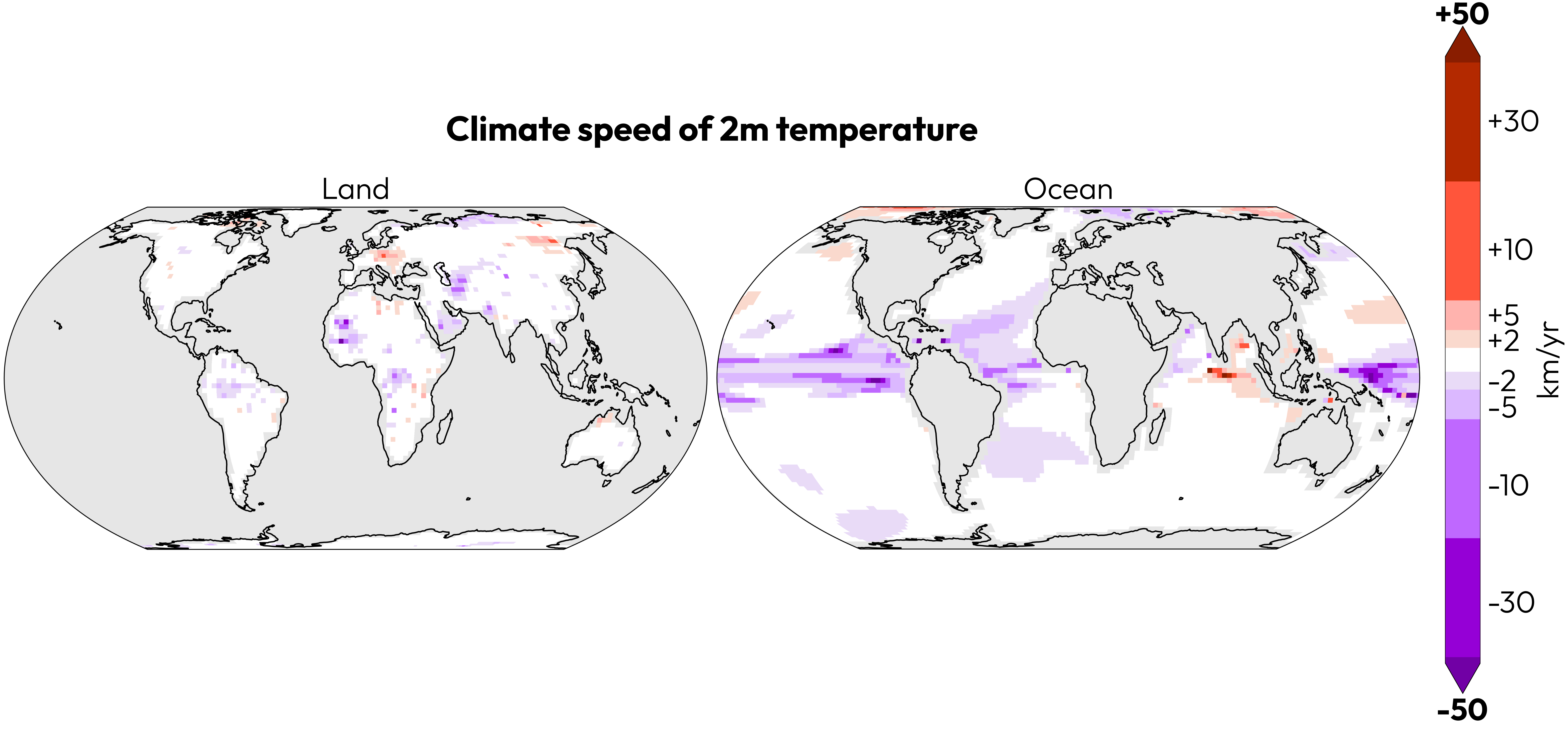
ARISE-DelayedStart
Starting in 2045, *return* global mean temperature to 1.37˚C
[10 members]

Last Millennium[16] - *1000-year simulation from 850-1849*

- All in Community Earth System Model with Whole Atmosphere Community Climate Model CESM2(WACCM6)
- Use a control algorithm at off-equatorial locations to manage multiple climate targets
- **Key point:** ARISE-1.5 *maintains temperature*—ARISE-DelayedStart is similar in design, but *begins 10 years later*

Climate speeds are small during the Last Millennium

(Ten 20-yr periods) Last Millennium



from Hueholt et al. (2023), under revision

Climate speeds in ARISE-1.5 where temperature is maintained are small

- Climate speeds over land very similar in magnitude to Last Millennium

from Hueholt et al. (2023), under revision

Climate speeds in ARISE-1.5 where temperature is maintained are small

- Climate speeds over land very similar in magnitude to Last Millennium
- Negative forcing overall, as 2035 deployment year is slightly above the 1.5 ˚C temperature target

from Hueholt et al. (2023), under revision

Climate speeds in SSP2-4.5 are large nearly globally and positive in sign

- Largest climate speeds over the tropics, particularly the tropical ocean (small spatial gradient)
- Climate speeds also high in the Arctic, where the warming rate is highest

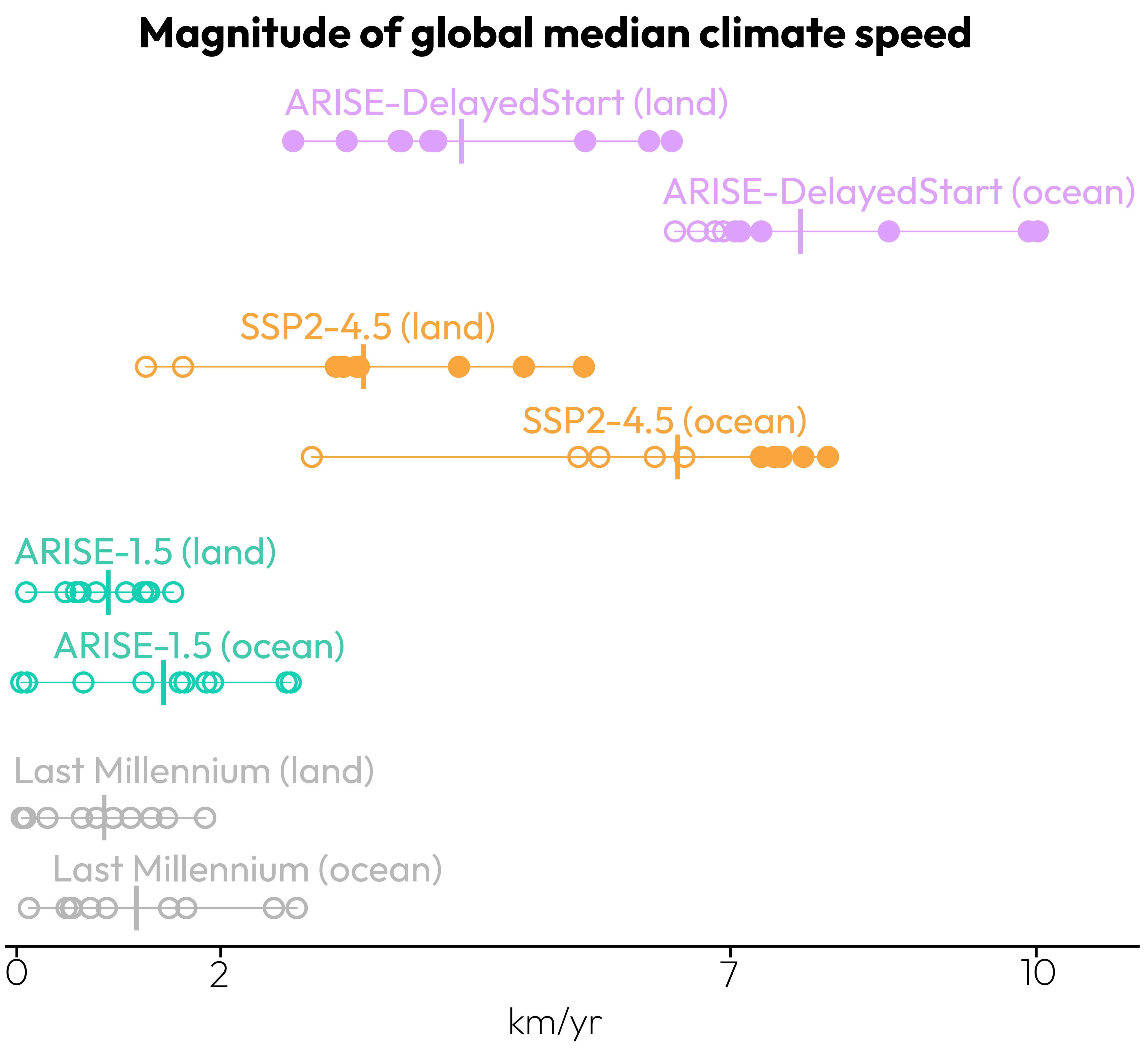
from Hueholt et al. (2023), under revision

Climate speeds in ARISE-DelayedStart are large and negative in sign globally

- Magnitudes as large or larger than SSP2-4.5 with no SAI at all
- Potentially dangerous climate speeds over >66% of land area

from Hueholt et al. (2023), under revision

Climate variability still plays an important role in the presence of forcing from SAI



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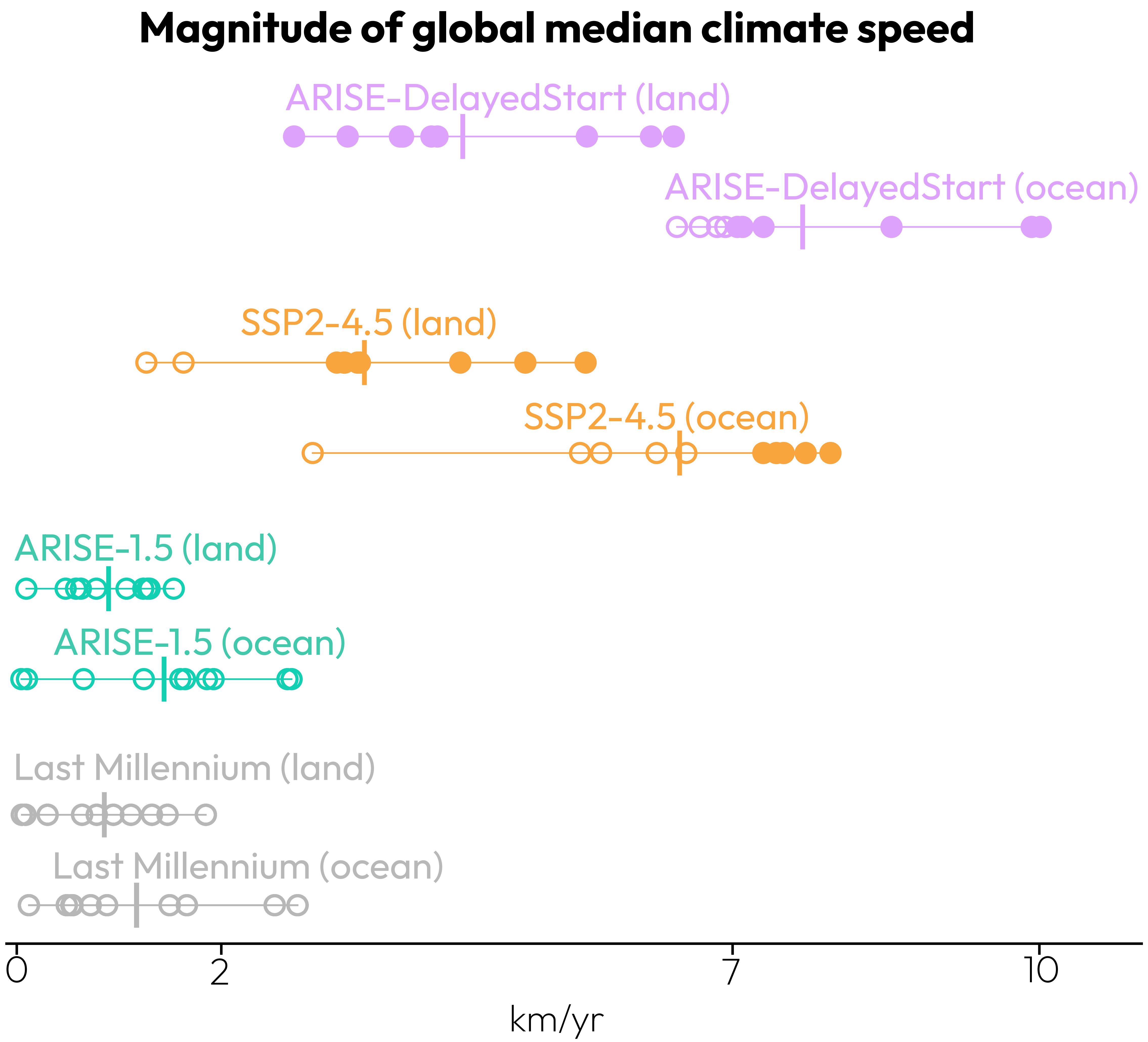
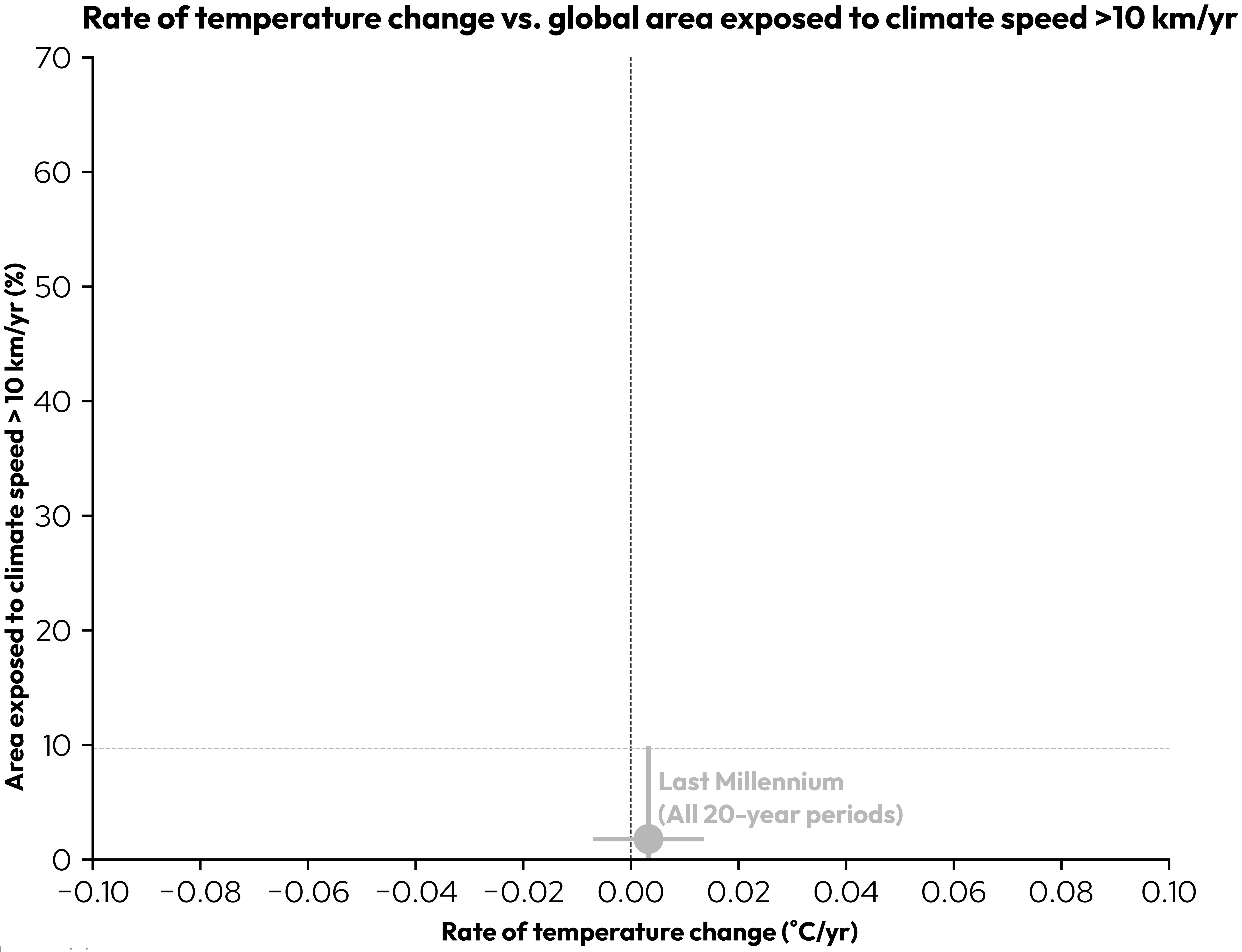


- ARISE-1.5 is statistically indistinguishable from Last Millennium on the planetary scale
- No overlap between ARISE-DelayedStart and ARISE-1.5 or Last Millennium

from Hueholt et al. (2023), under revision

Climate speeds provide one way to think about relative risk between scenarios



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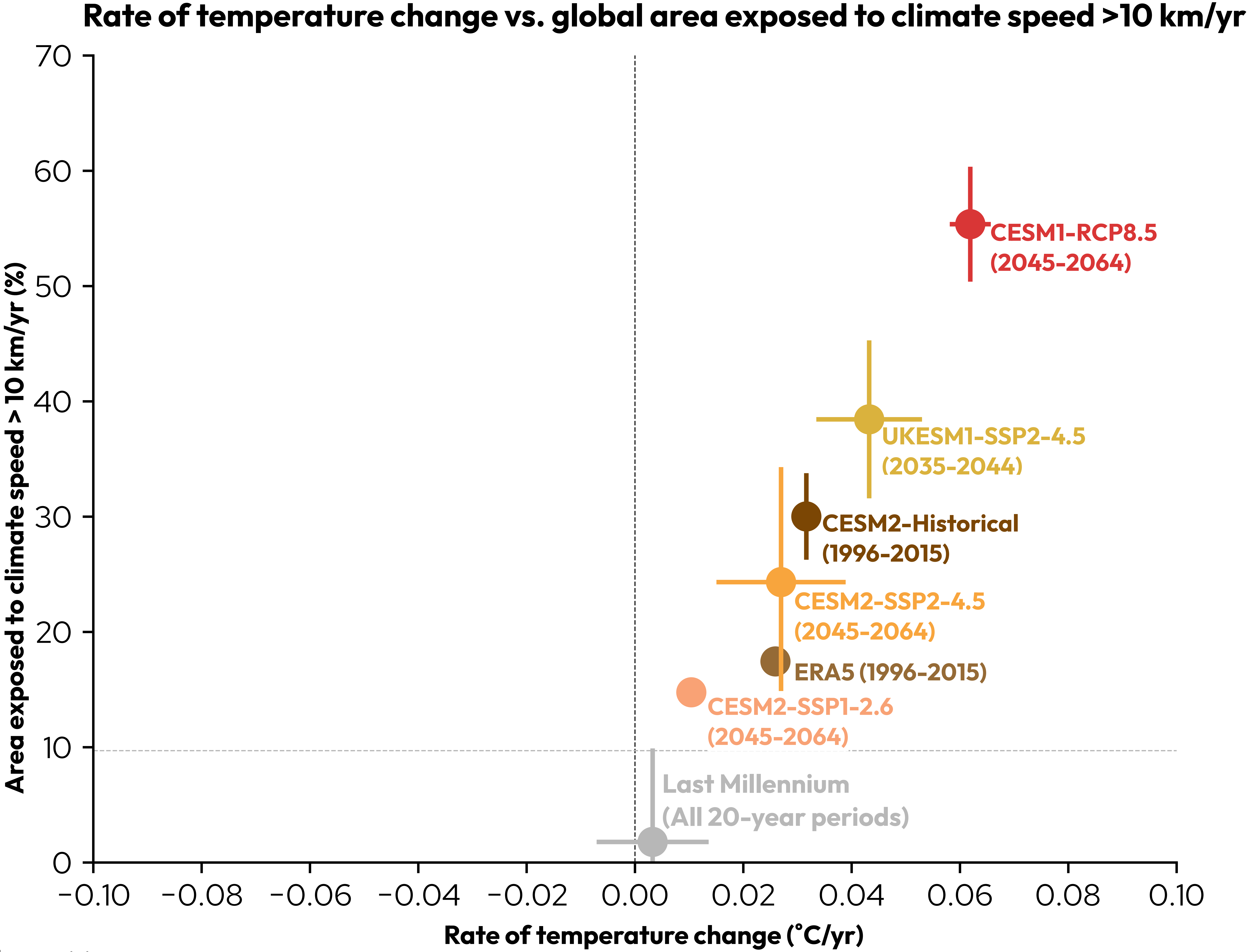
Future climate change and recent historical above Last Millennium variability on right



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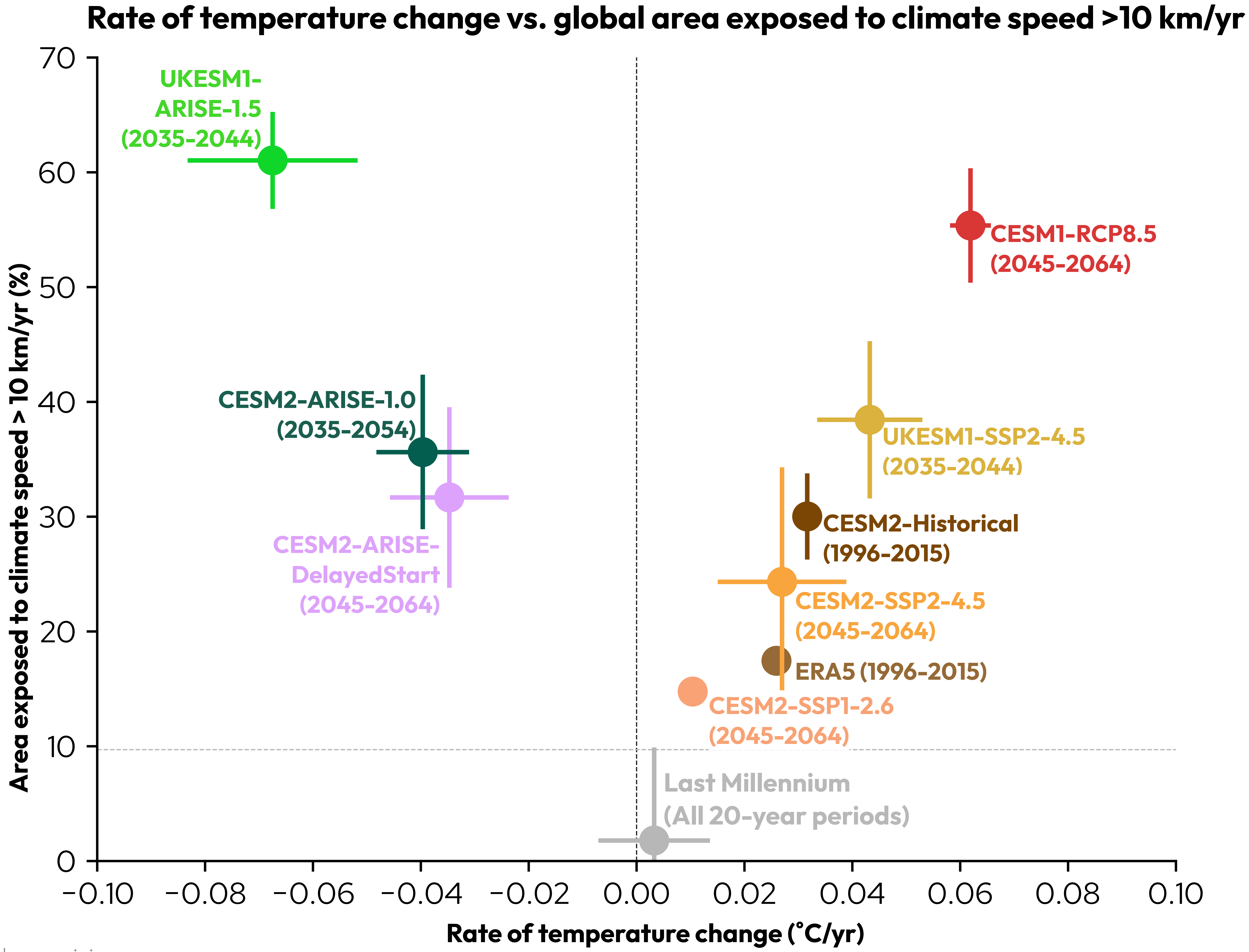
Rapid temperature reduction above Last Millennium variability on left side



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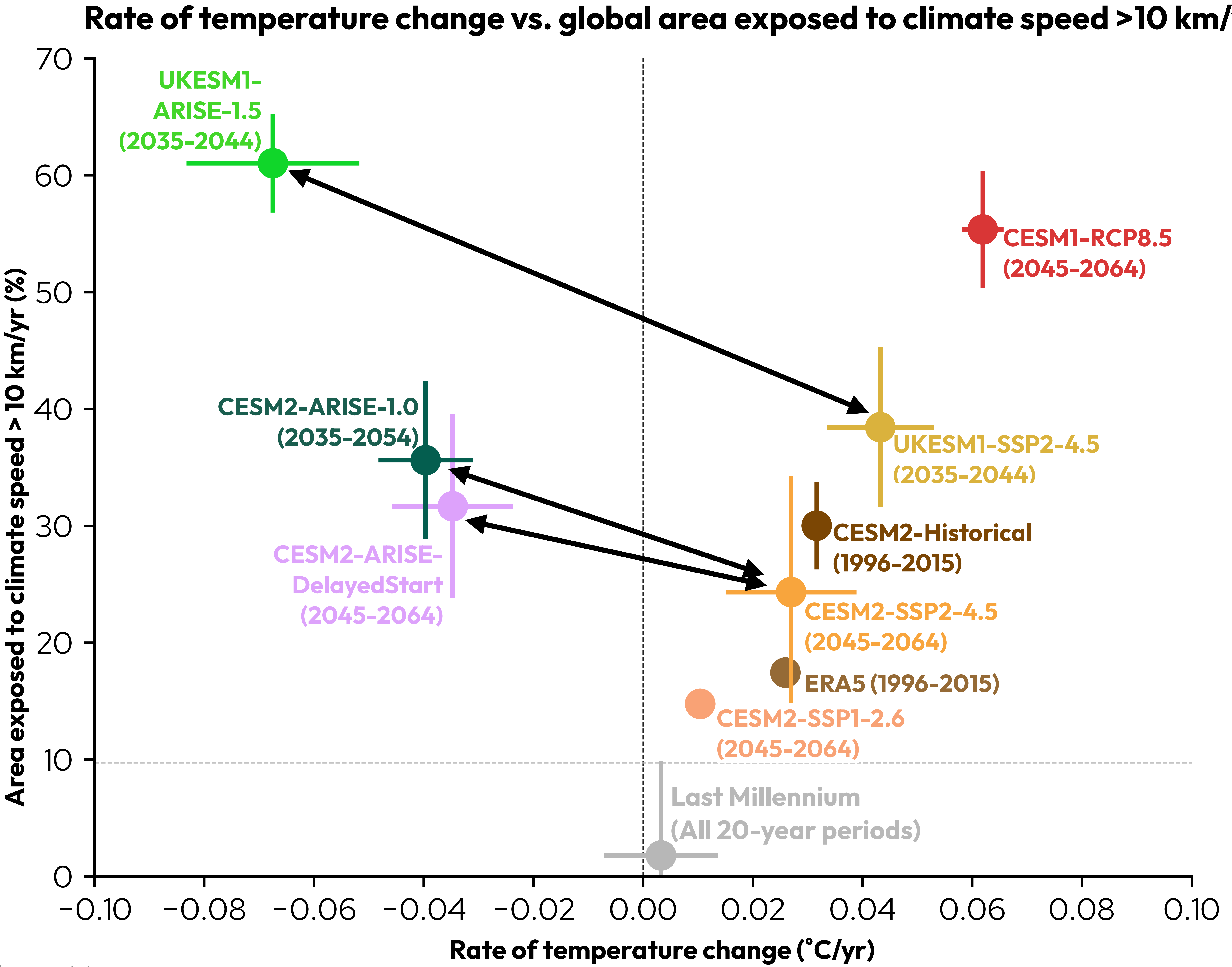
ARISE allows us to connect rapid temperature reduction to specific strategic choices



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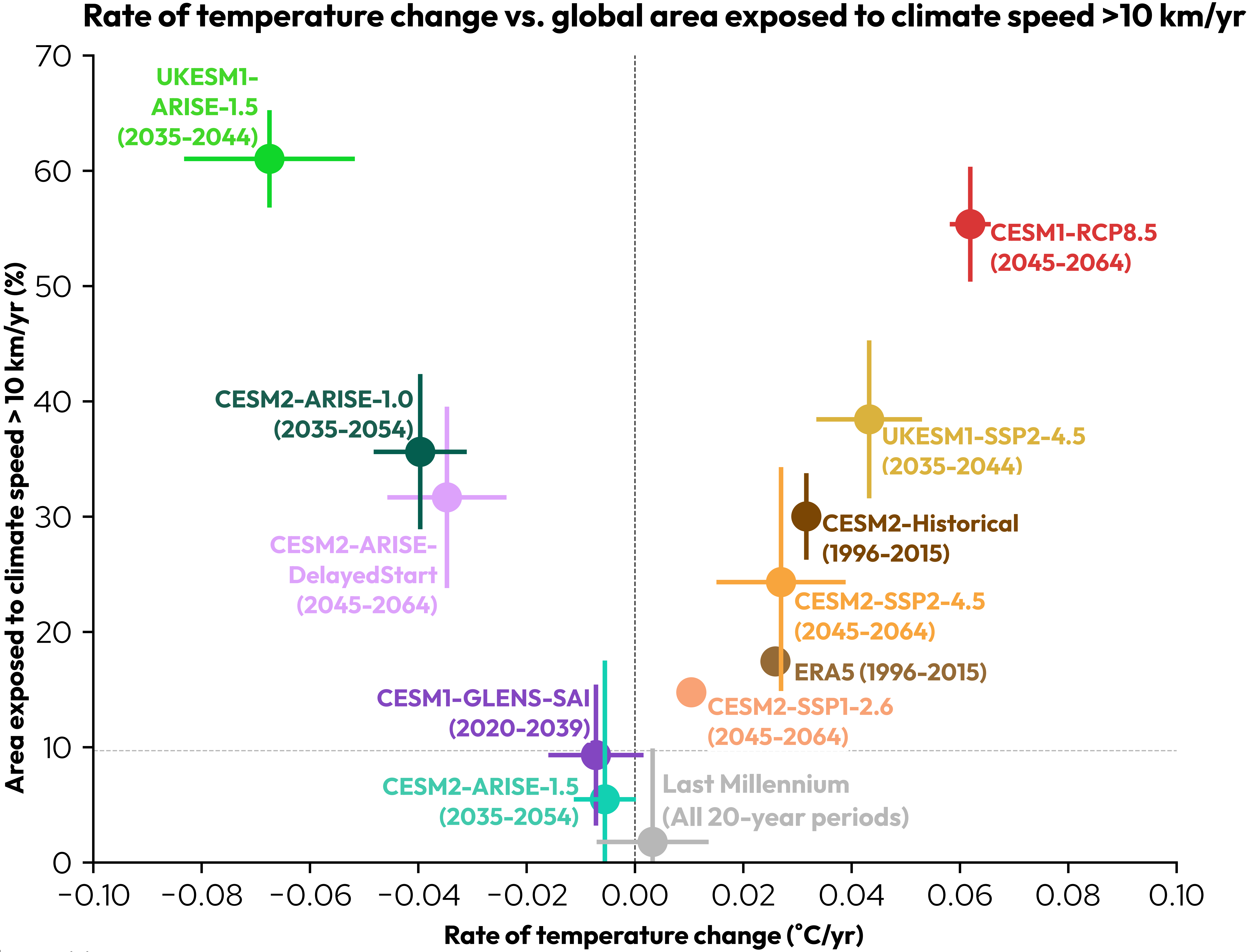
Temperature maintenance ("peak-shaving") within Last Millennium variability



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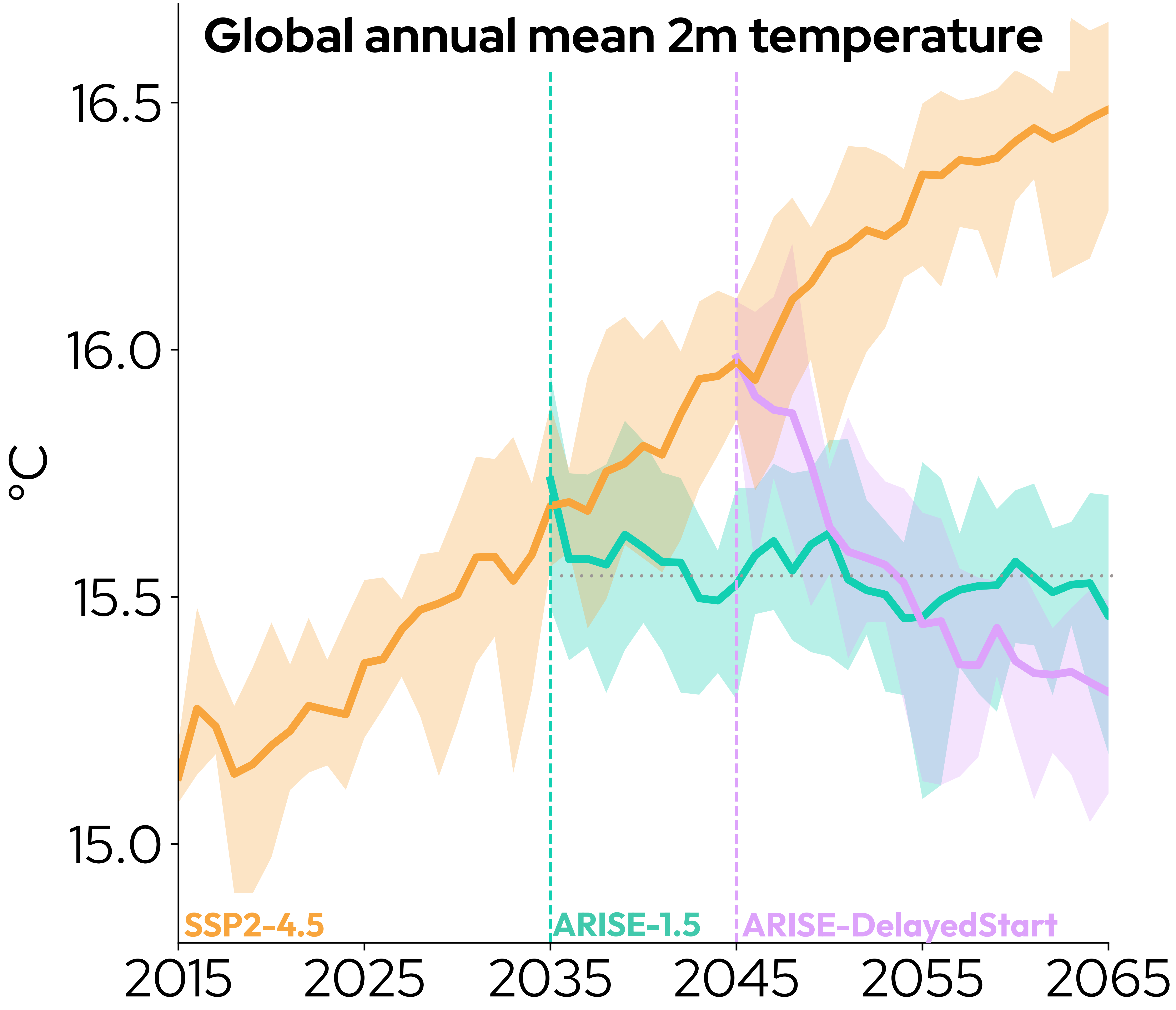
At a very high level, this all comes from the temperature trends



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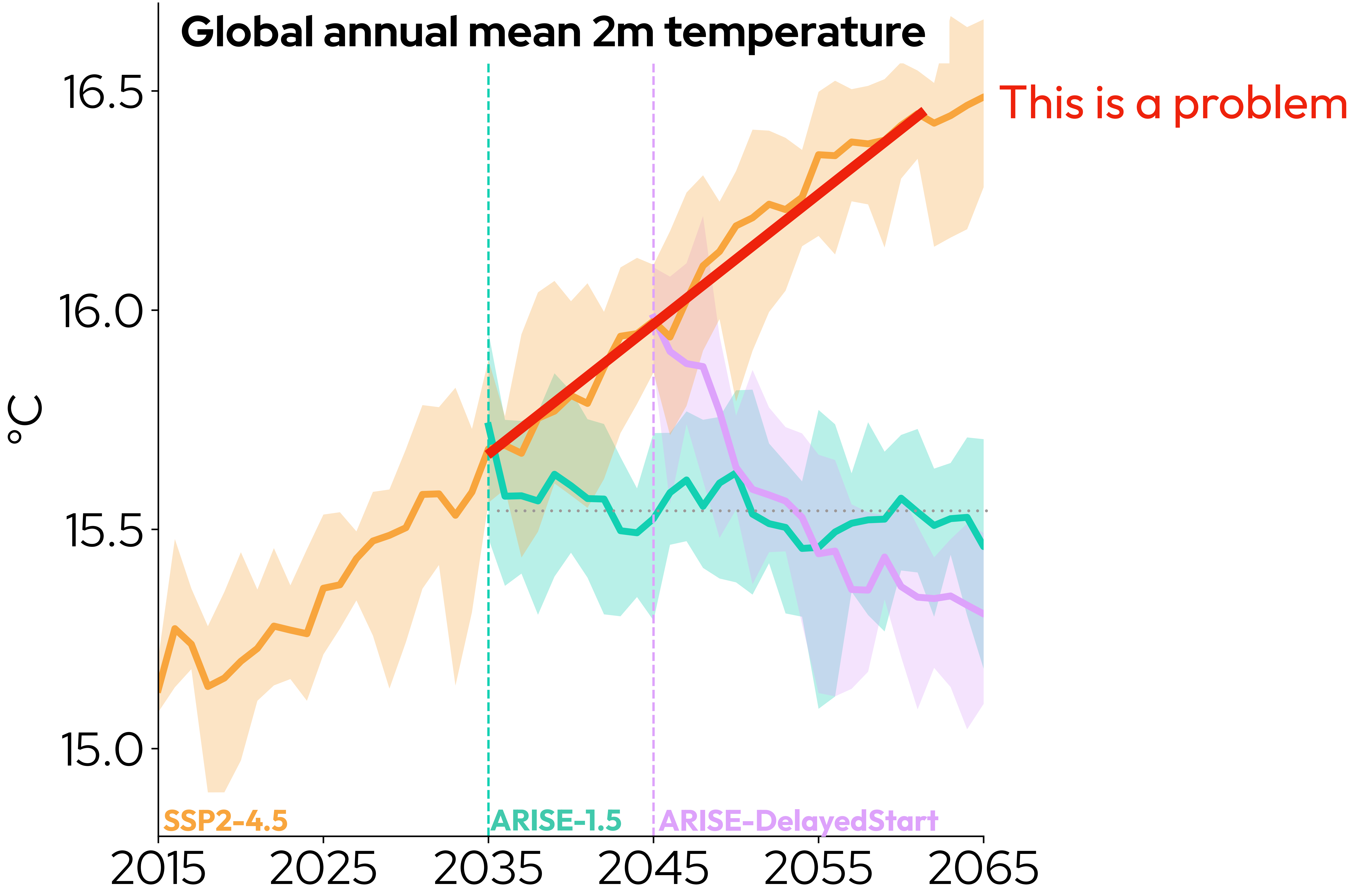

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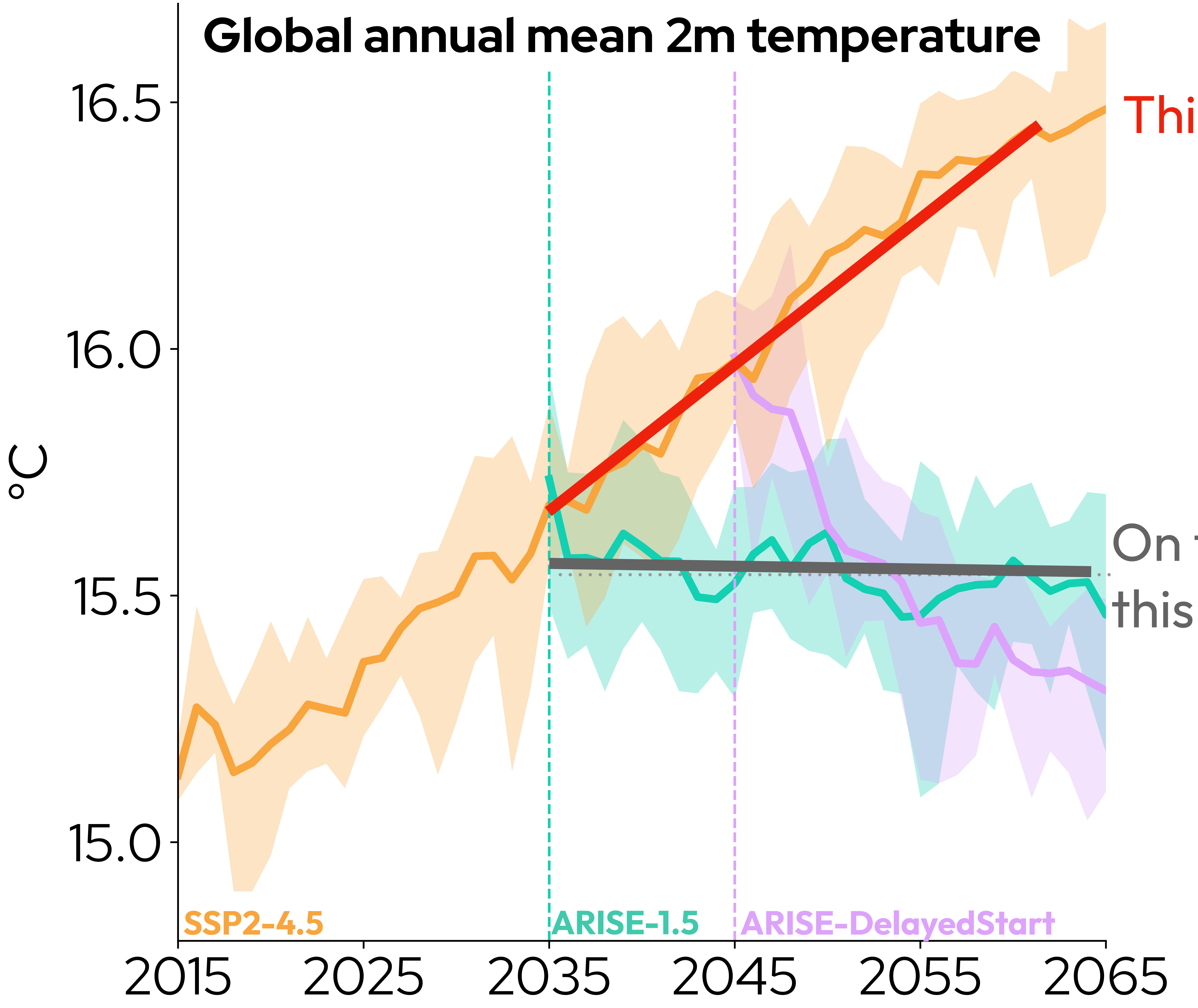

This is a problem

On this one specific metric, this might not be so bad

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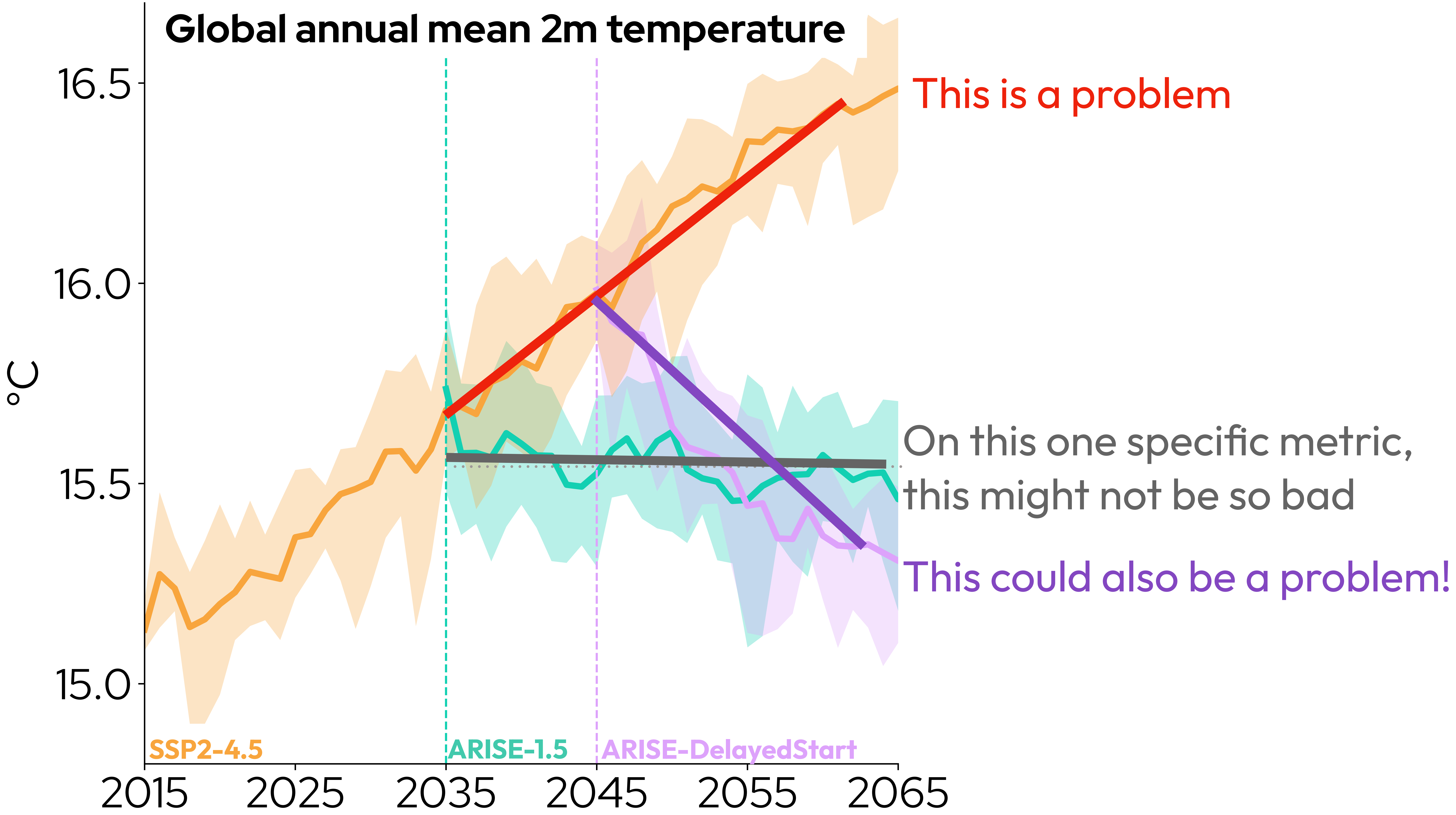
At a very high level, this all comes from the temperature trends



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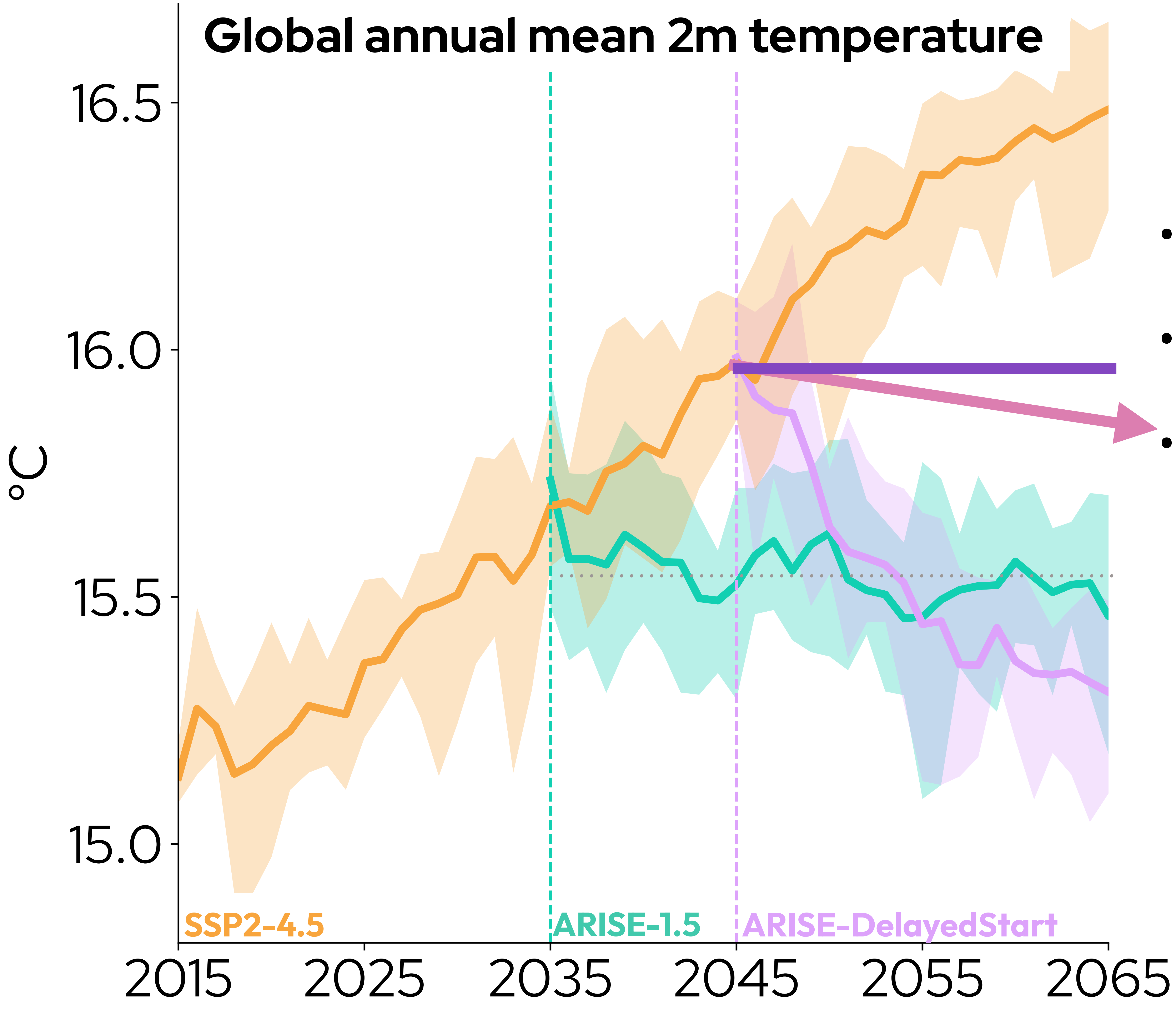

- Could imagine scenarios to avoid "deployment shock"
- **"Delayed start maintenance"** — post-2035 deployment, higher target
- **"Slow start"** — modulate start to slow climate speeds

from Hueholt et al. (2023), under revision

Summary

- ARISE simulations allow for outcomes in different scenarios to be connected to specific strategic decisions
- Climate speeds when global mean temperature is maintained with SAI (ARISE-1.5) are similar to those experienced over the Last Millennium
- A similar SAI strategy but with deployment delayed by 10 years (ARISE-DelayedStart) yields large planetary-scale climate speeds
- The climate speeds experienced during ARISE-DelayedStart are far beyond Last Millennium variability, and greater than climate change with no SAI
- Avoiding potentially dangerous climate speeds helps constrain scenario design

Thank you for listening! Questions?

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Preprint: doi.org/10.21203/rs.3.rs-3463352/v1

Footnotes

1. Loarie et al. 2009 "The velocity of climate change"
2. Parmesan and Yohe 2003 "A globally coherent fingerprint of climate change impacts across natural systems"
3. Chen et al. 2011 "Rapid Range Shifts of Species Associated with High Levels of Climate Warming"
4. Poloczanska et al. 2013 "Global imprint of climate change on marine life"
5. Lenoir et al. 2020 "Species better track climate warming in the oceans than on land"
6. Trisos et al. 2018 "Potentially dangerous consequences for biodiversity of solar geoengineering implementation and termination"
7. Brito-Morales et al. 2018 "Climate Velocity can Inform Conservation in a Warming World"
8. Burrows et al. 2014 "Geographical limits to species-range shifts are suggested by climate velocity"
9. García Molinos et al. 2016 "Climate velocity and the future global redistribution of marine biodiversity"
10. NASEM 2021 "Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance"
11. UNEP 2023 "One Atmosphere: An independent expert review on Solar Radiation Modification research and deployment"
12. McCusker et al. 2014 "Rapid and extensive warming following cessation of solar radiation management"
13. Parker and Irvine 2018 "The Risk of Termination Shock from Solar Geoengineering"
14. Richter et al. 2022 "Assessing Responses and Impacts of Solar climate intervention on the Earth system with stratospheric aerosol injection (ARISE-SAI): protocol and initial results from the first simulations"
15. Brody et al. 2024 "Kicking the Can Down the Road: Understanding the Effects of Delaying the Deployment of Stratospheric Aerosol Injection"
16. Otto-Bliesner et al. 2023 "Dataset: CESM2-WACCM6ma Last Millennium"

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