Exploring the Influence of Internal Climate Variability and Forced Change on Arctic Greening

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Polar Climate Winter Working Group
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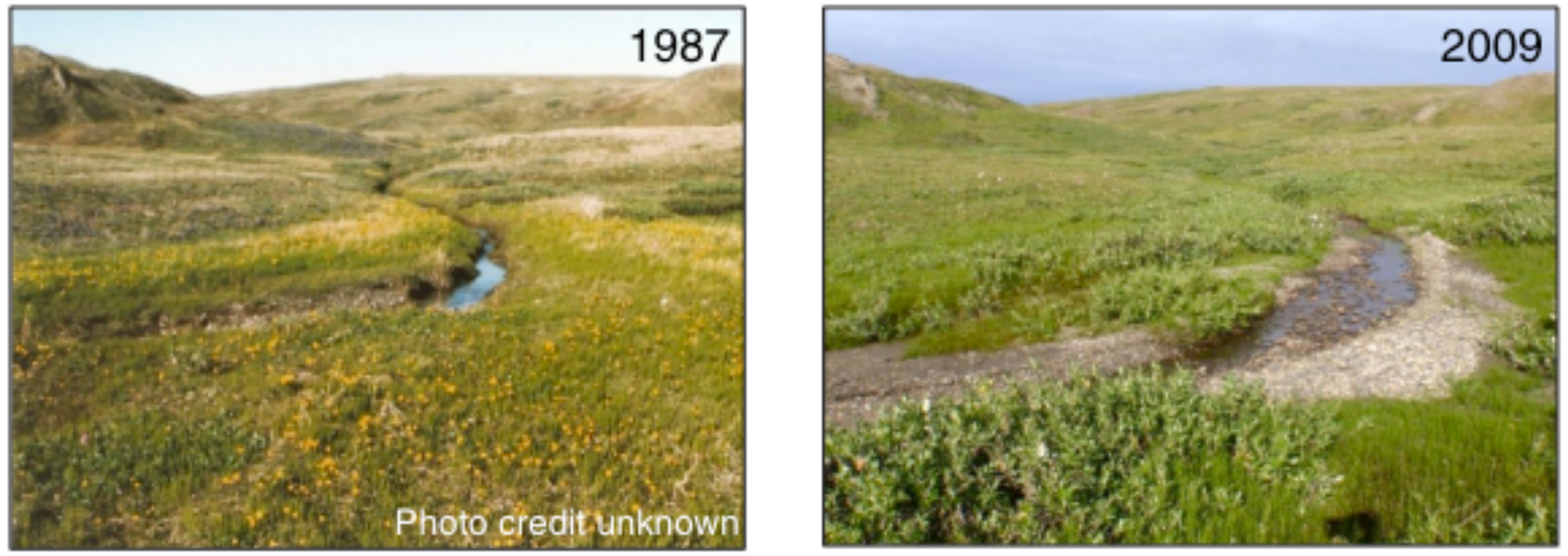
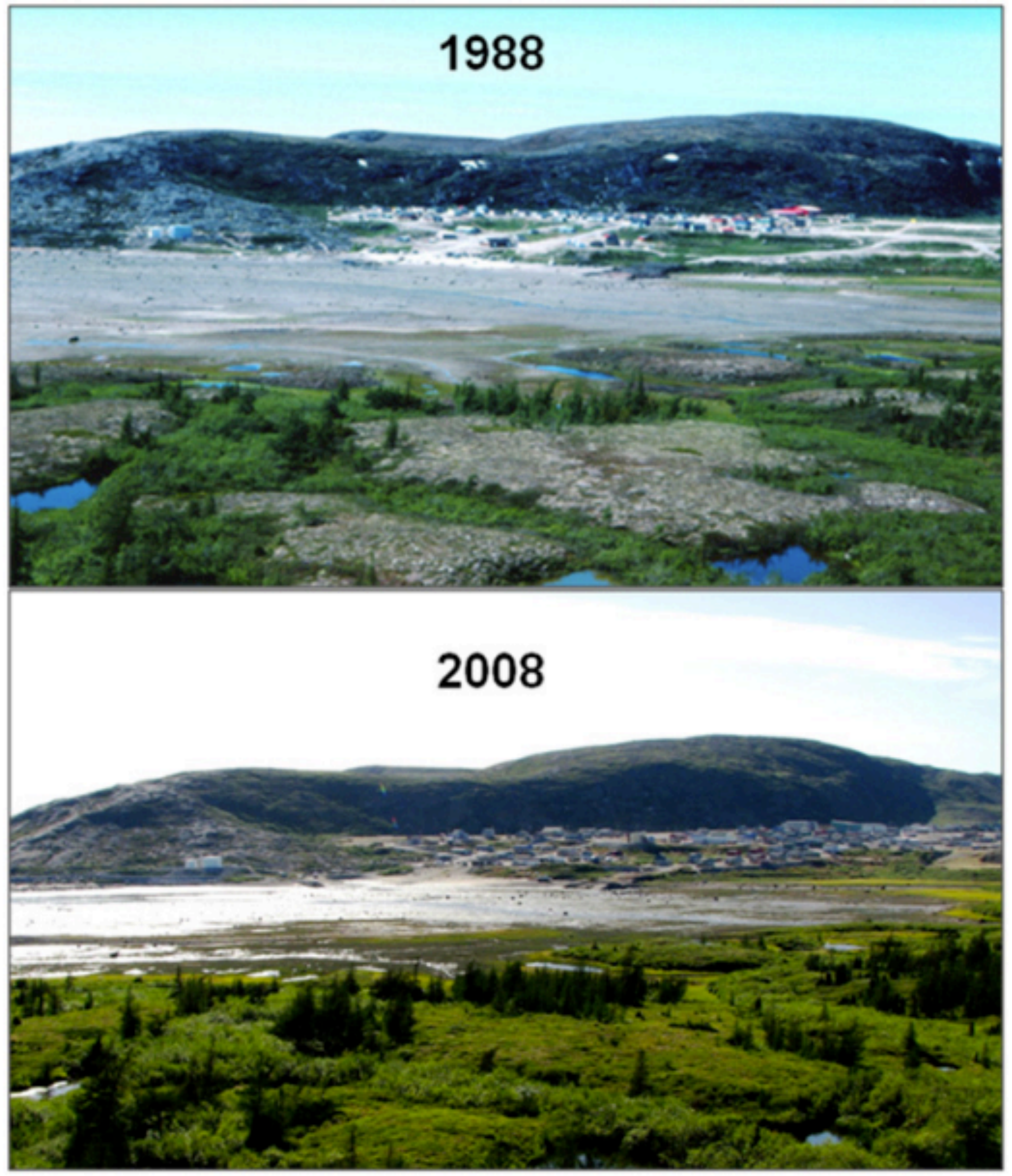


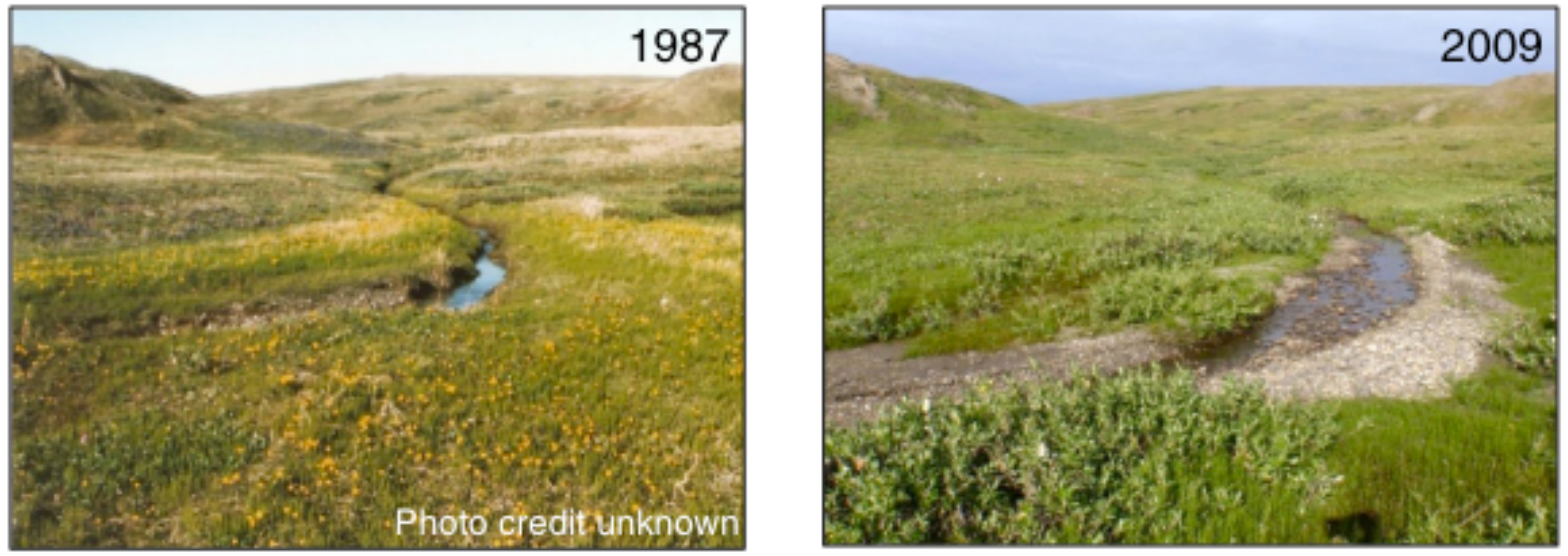
Myers-Smith et al. 2019



Tremblay et al. 2012

Two processes associated with Arctic greening

- Increased productivity in existing ecosystems
- Ecosystem state change as plants expand poleward
- Arctic greening is driven by anomalies in *growing degree days*—a measure of growing season warmth



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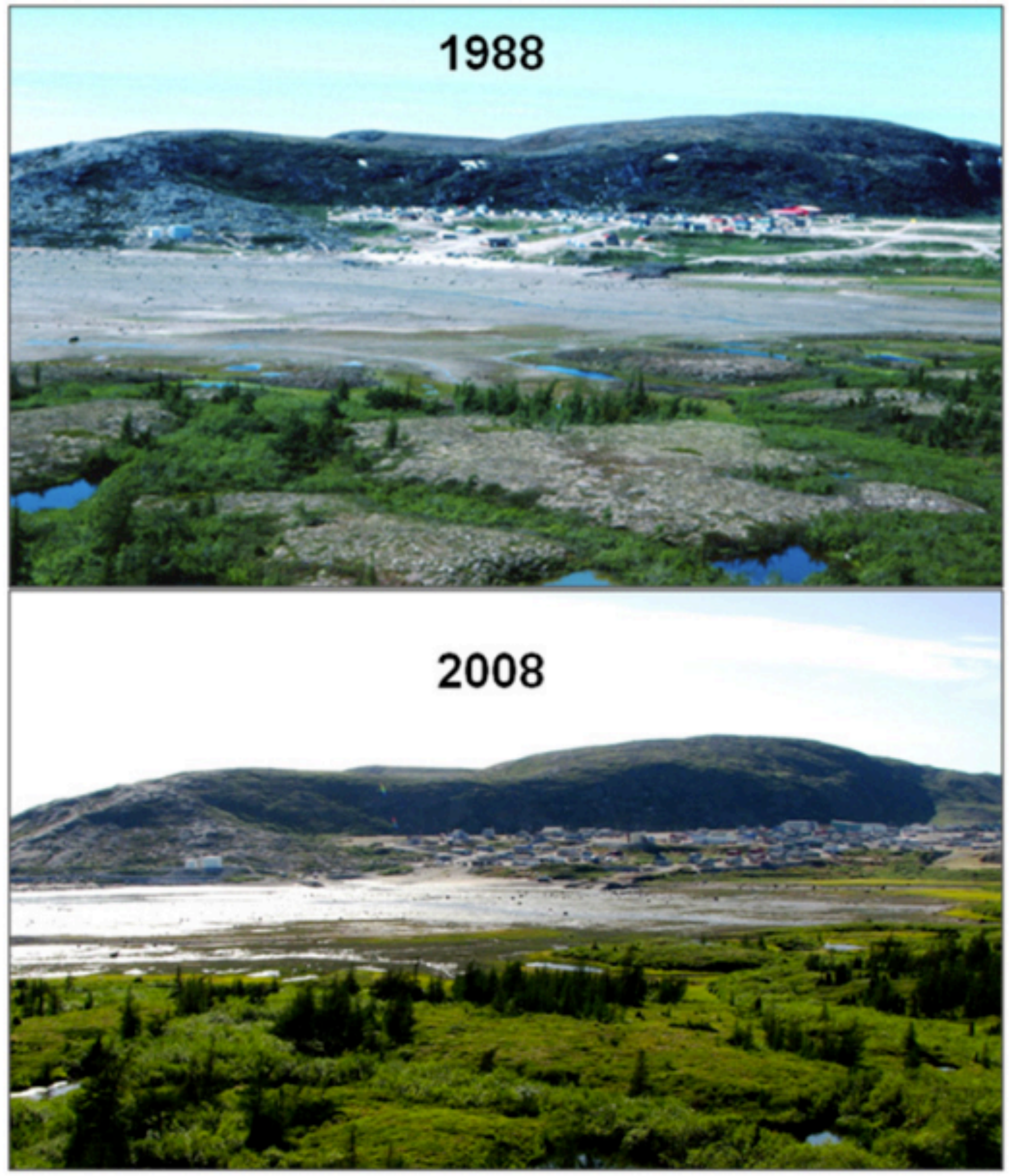

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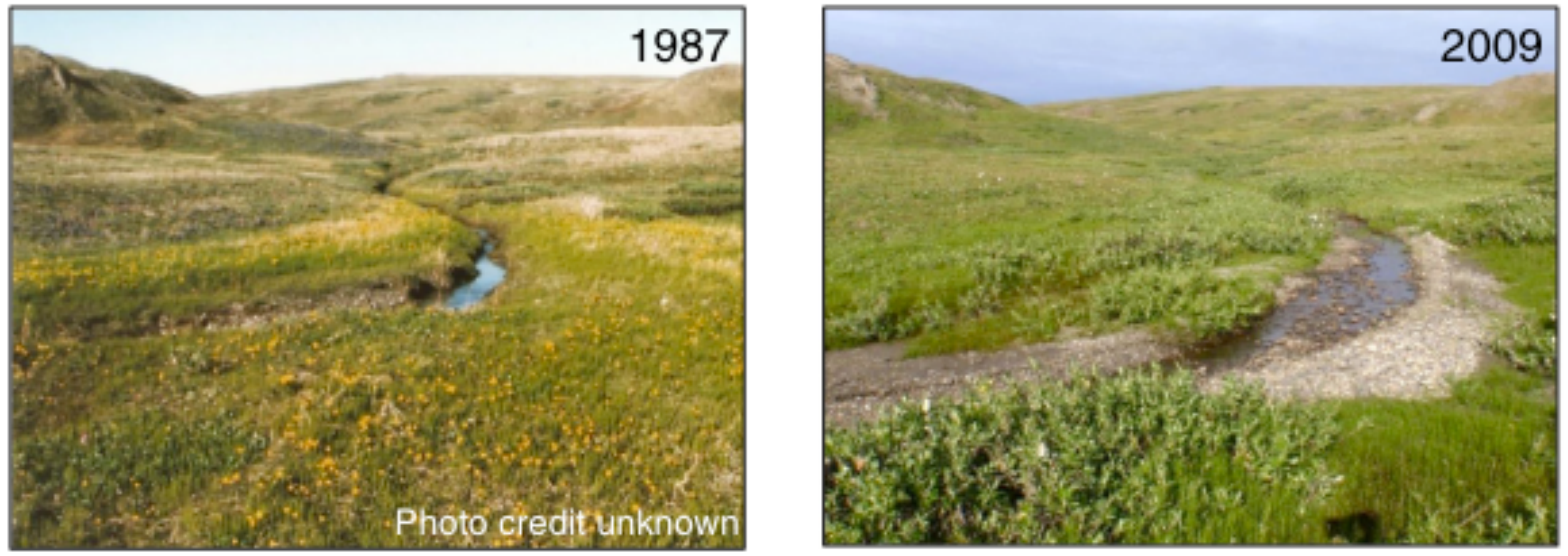
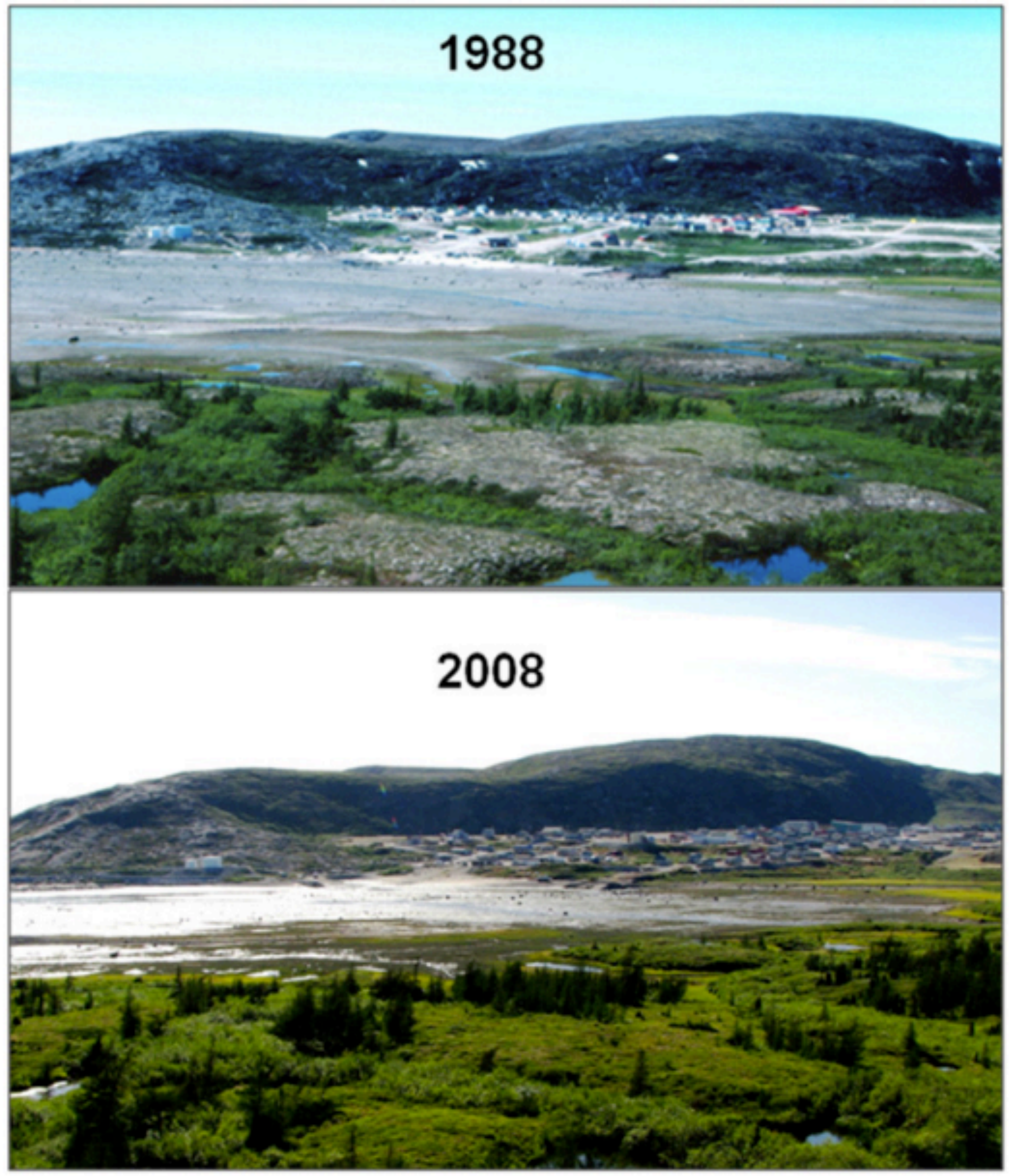


Myers-Smith et al. 2019

This analysis is made possible by extensive existing fieldwork! e.g.,:

Sturm et al. 2001 "Increasing shrub abundance in the Arctic"
Jia et al. 2003 "Greening of arctic Alaska, 1981–2001"
Caccianaga & Payette 2006 "Recent advance of white spruce (Picea glauca) in the coastal tundra of the eastern shore of Hudson Bay (Québec, Canada)"
MacDonald et al. 2007 "Climate change and the northern Russian treeline zone"
Harsch et al. 2009 "Are treelines advancing? A global meta-analysis of treeline response to climate warming"
Elmendorf et al. 2012 "Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time"
Tremblay et al. 2012 "Recent expansion of erect shrubs in the Low Arctic: evidence from Eastern Nunavik"
Büntgen et al. 2015 "Temperature-induced recruitment pulses of Arctic dwarf shrub communities"
Myers-Smith et al. 2019 "Eighteen years of ecological monitoring reveals multiple lines of evidence for tundra vegetation change"
Berner et al. 2020 "Summer warming explains widespread but not uniform greening in the Arctic tundra biome"
Piao et al. 2020 "Characteristics, drivers and feedbacks of global greening"
Myers-Smith et al. 2020 "Complexity revealed in the greening of the Arctic"
Dial et al. 2022 "Sufficient conditions for rapid range expansion of a boreal conifer"
Huemmrich et al. 2023 "20 years of change in tundra NDVI from coupled field and satellite observations"
Karlsen et al. 2024 "Greening of Svalbard"

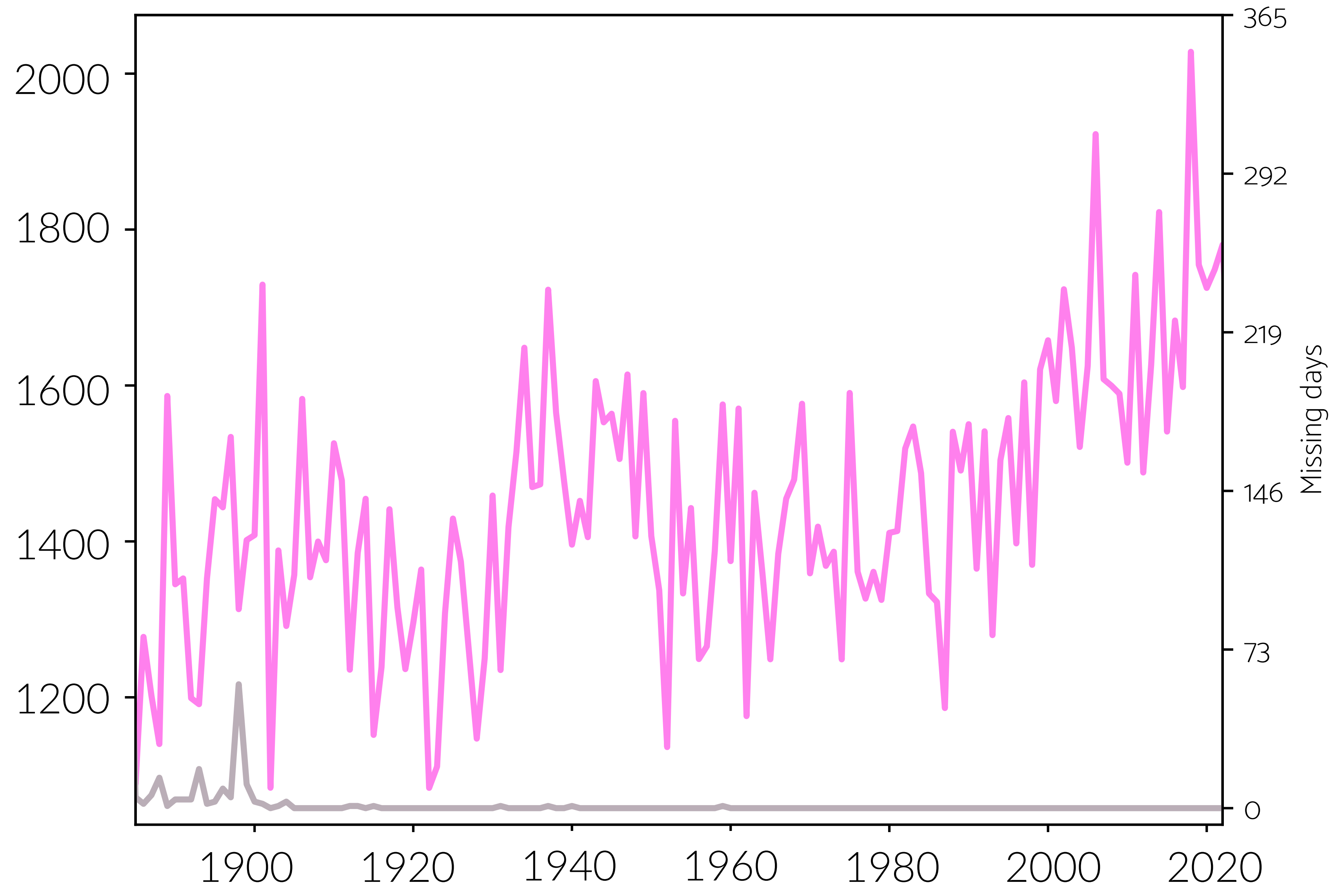


Tremblay et al. 2012

We study two phenomena in relation to growing degree days

- *Decadal anomalies* produce changes in ecosystem productivity and distribution which are largely elastic

Growing degree days in Boras, Sweden



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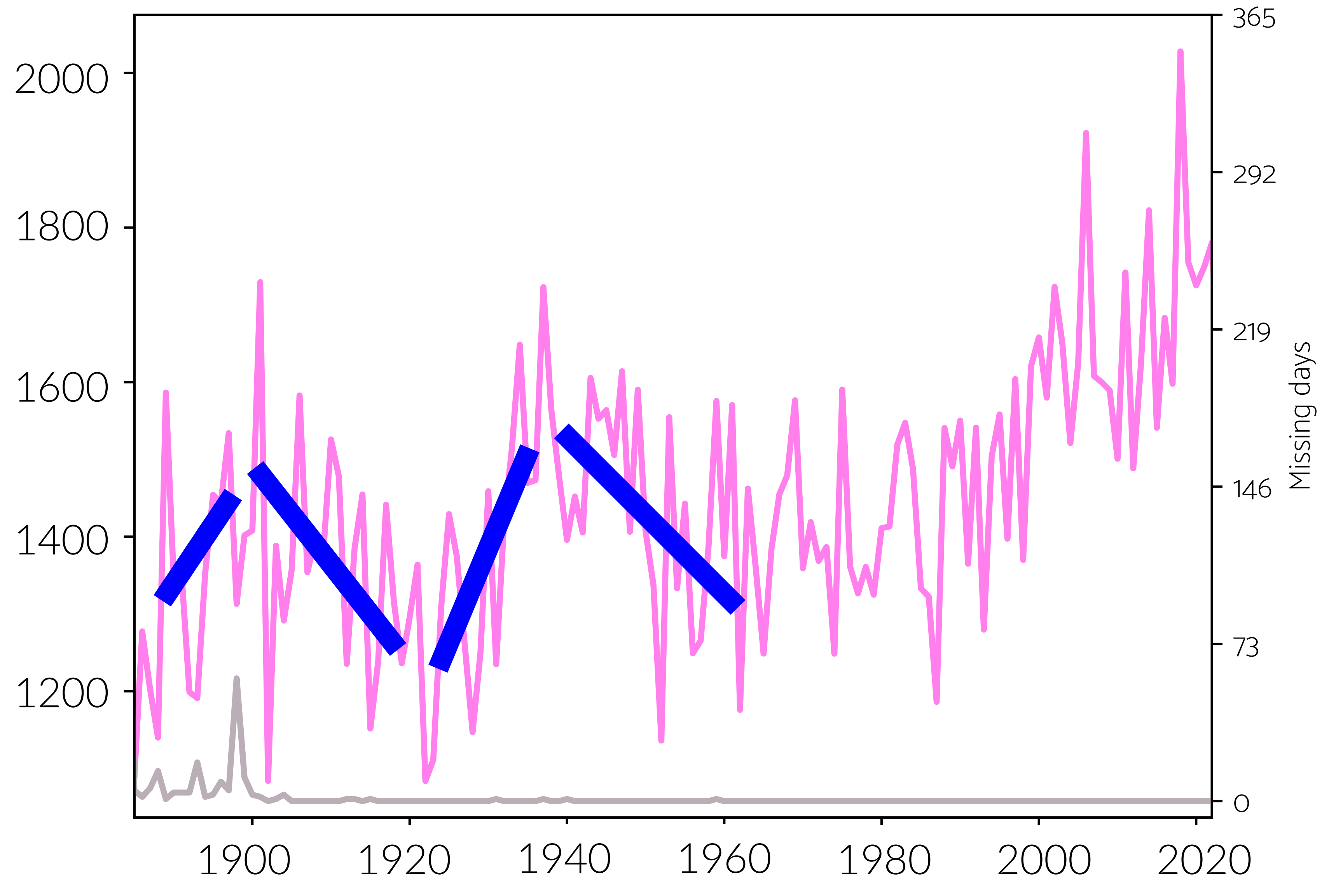

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- *Crossover* occurs when the warming trend becomes dominant, driving sustained change in ecosystem state

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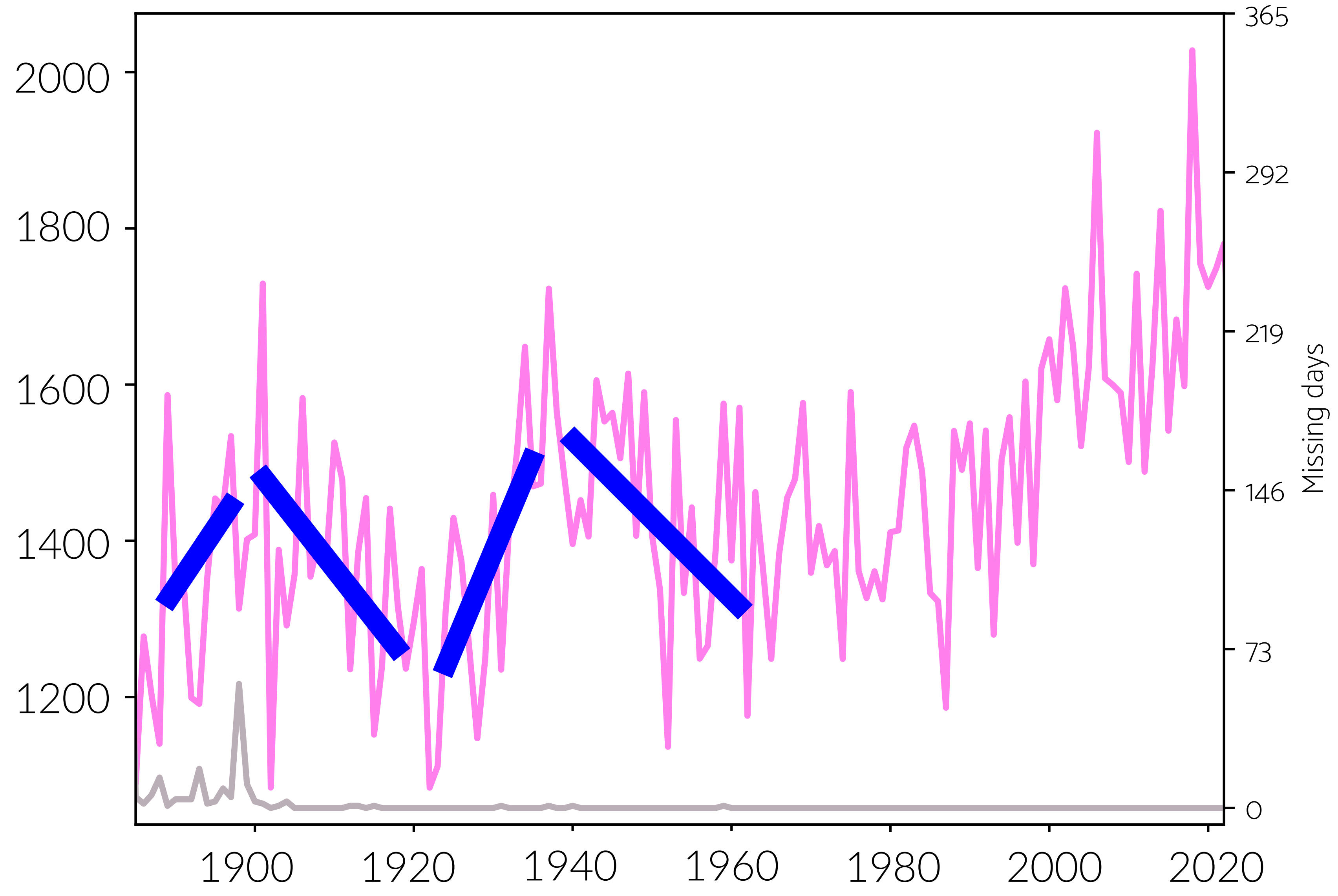

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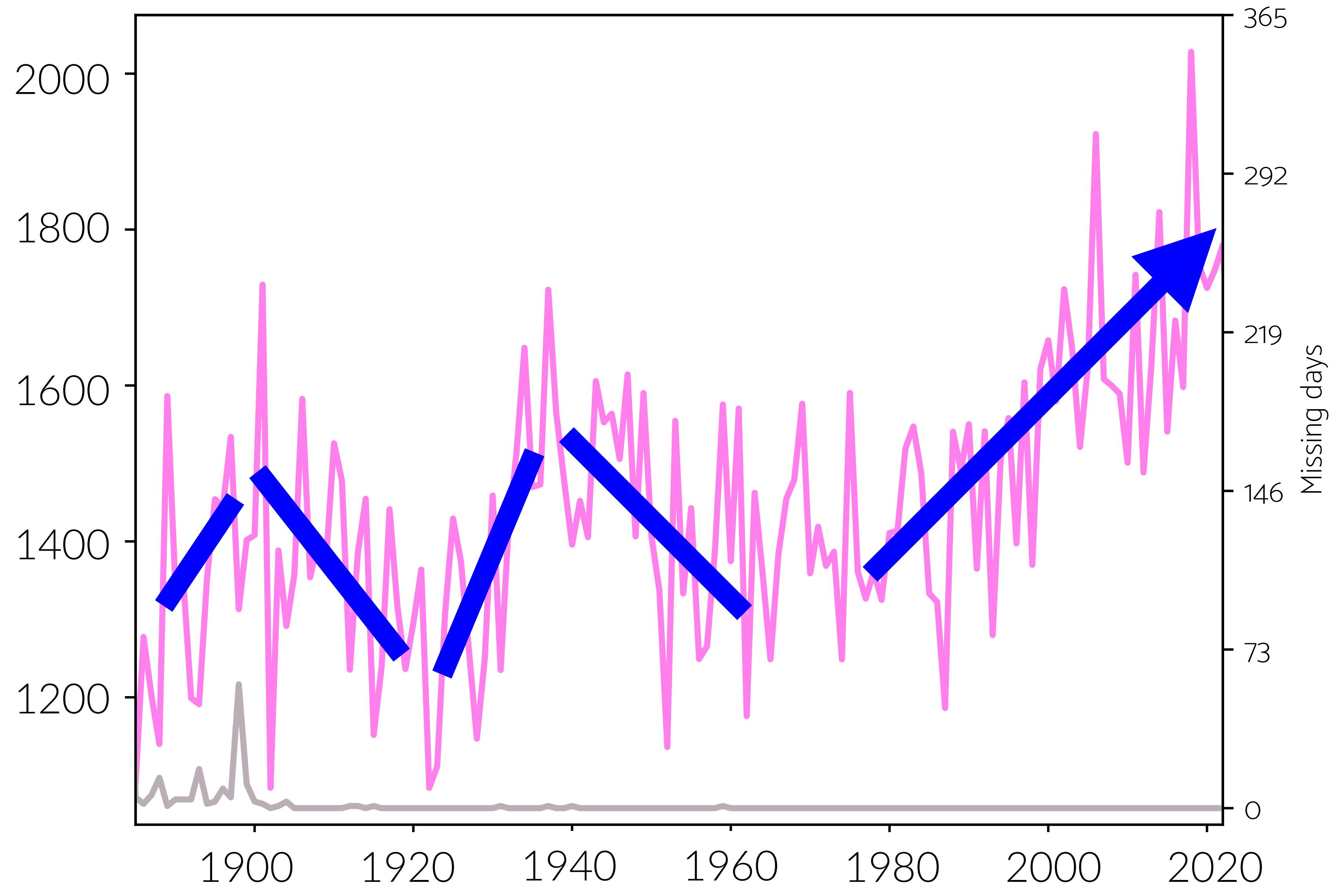

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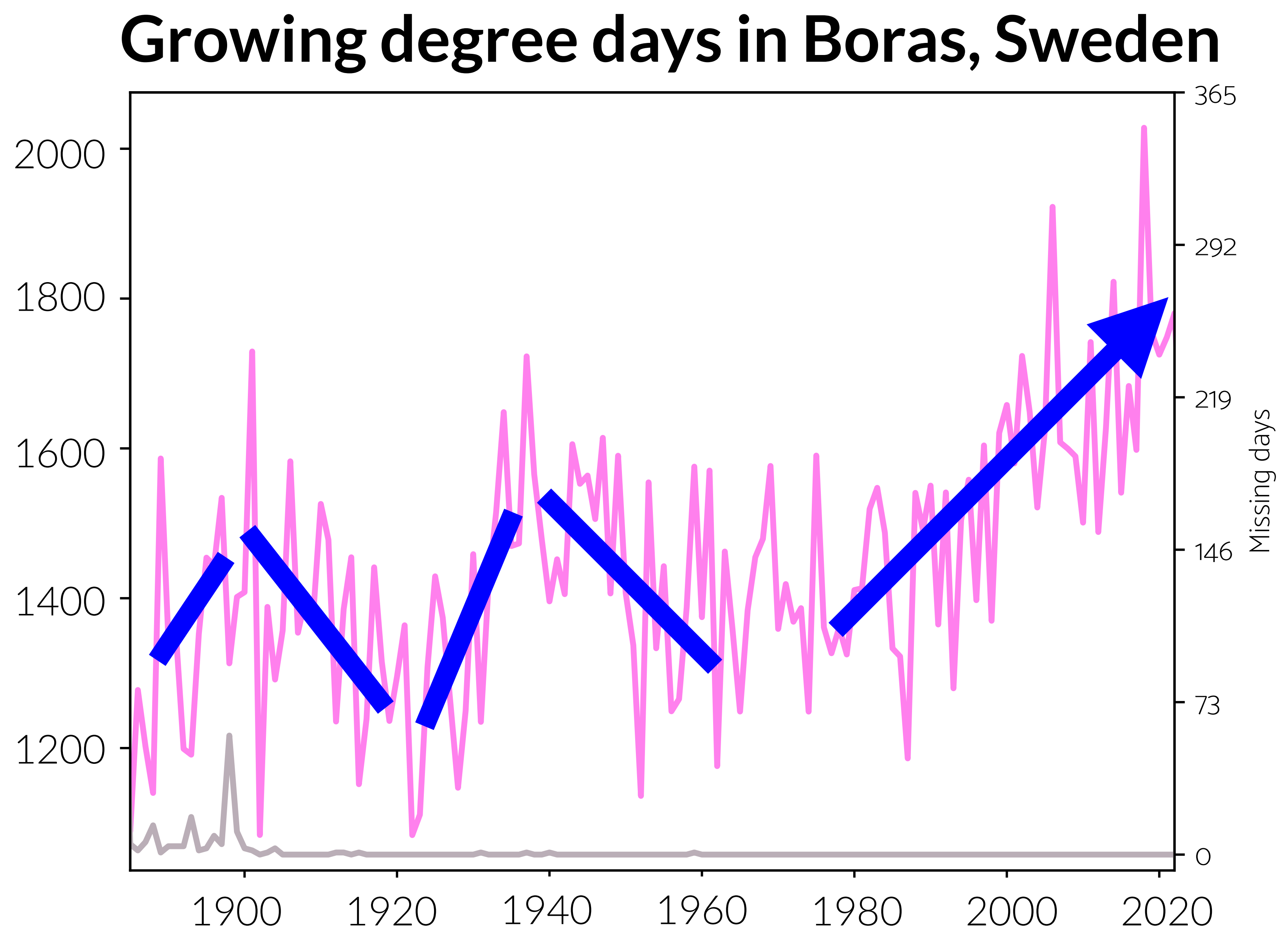
We study two phenomena in relation to growing degree days

- *Decadal anomalies* produce changes in ecosystem productivity and distribution which are largely elastic
- *Crossover* occurs when the warming trend becomes dominant, driving sustained change in ecosystem state
- We use the Community Earth System Model 2 (CESM2) Large Ensemble[1] (**LENS2**, 100 members, 1850-2100) to explore future changes
- The CESM2 Preindustrial control[2] (one member, 2000 years) provides a baseline of internal variability



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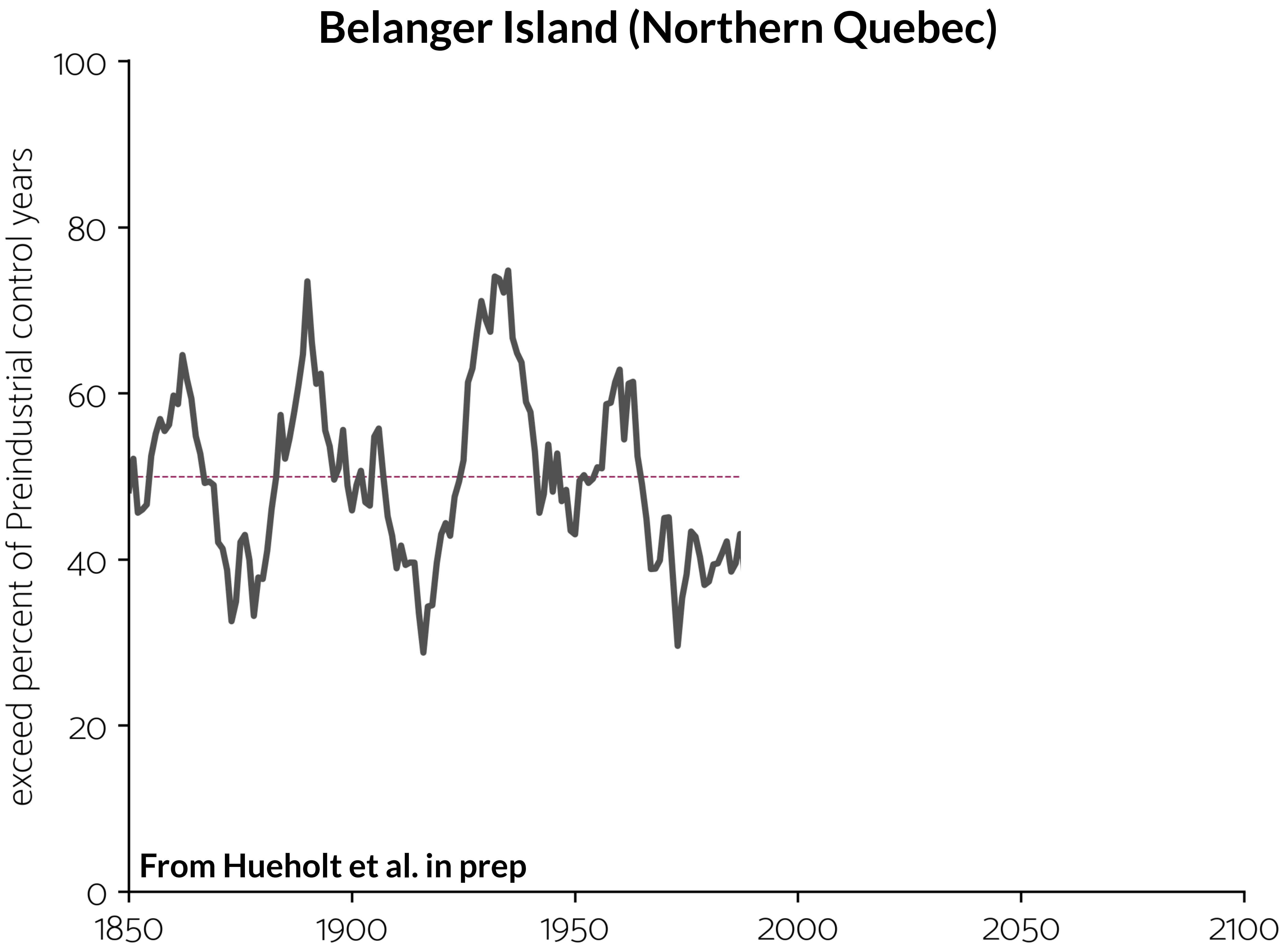
Considering "crossover"



- Count the percent of preindustrial samples exceeded in a year

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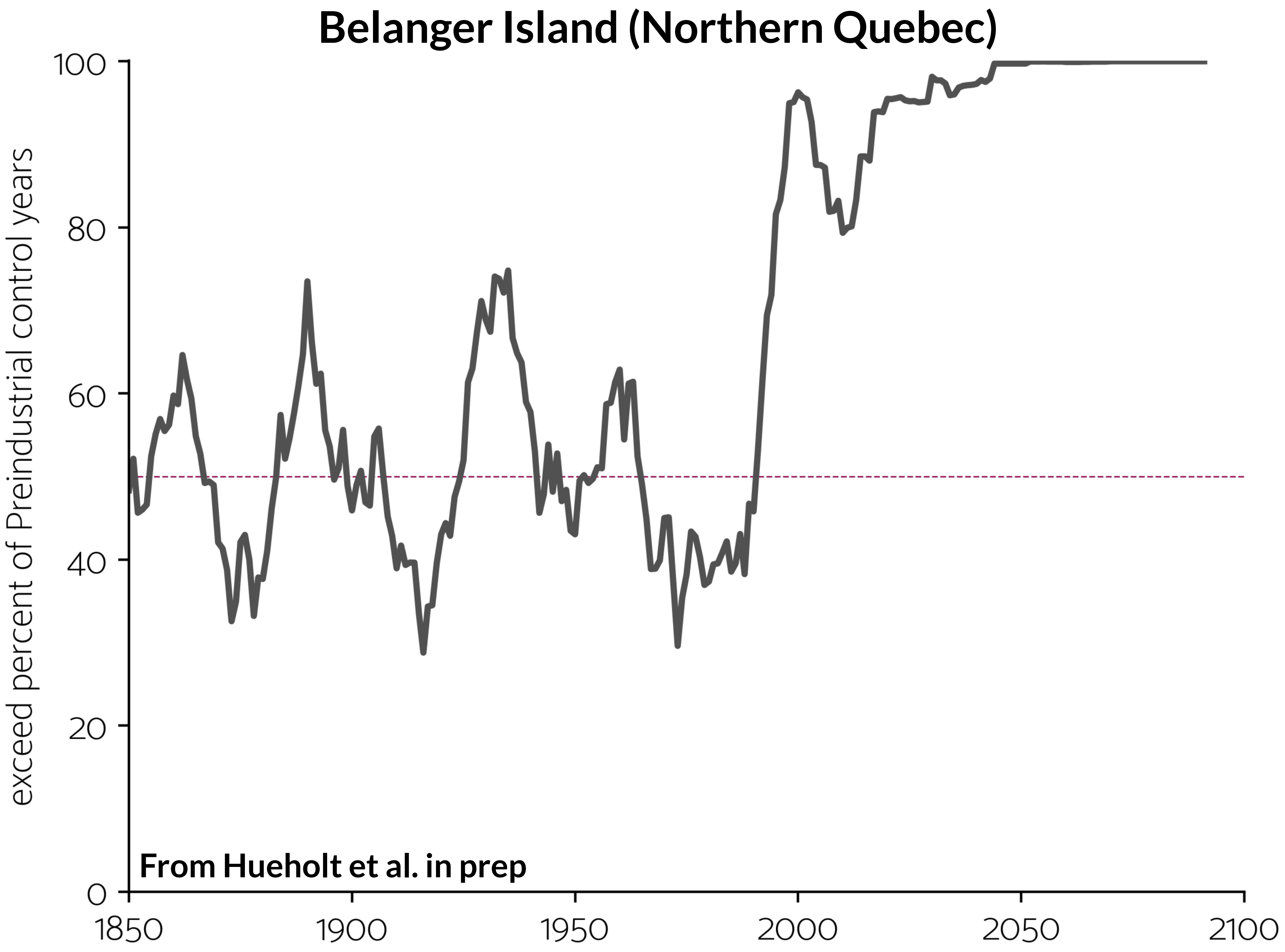

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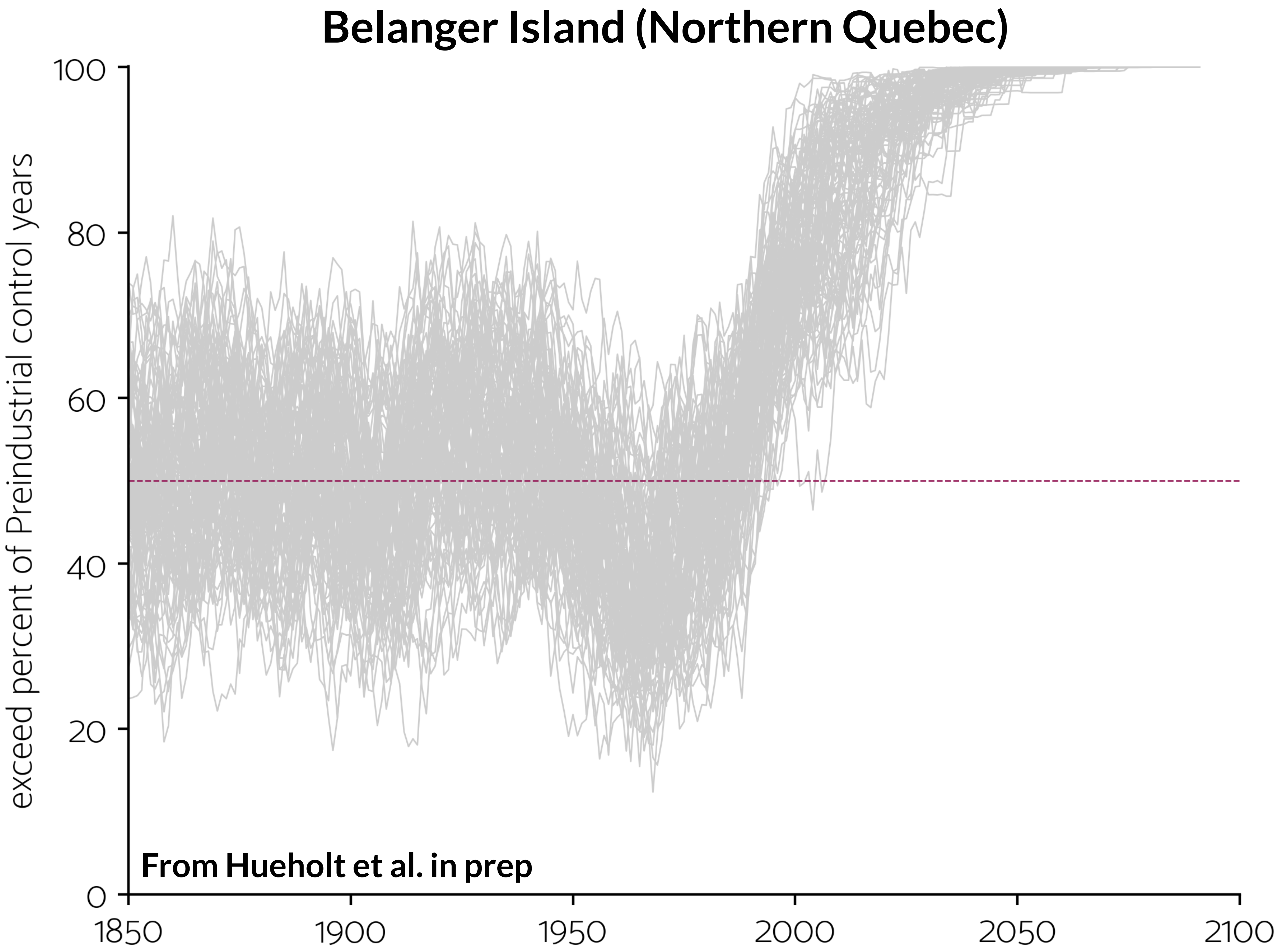

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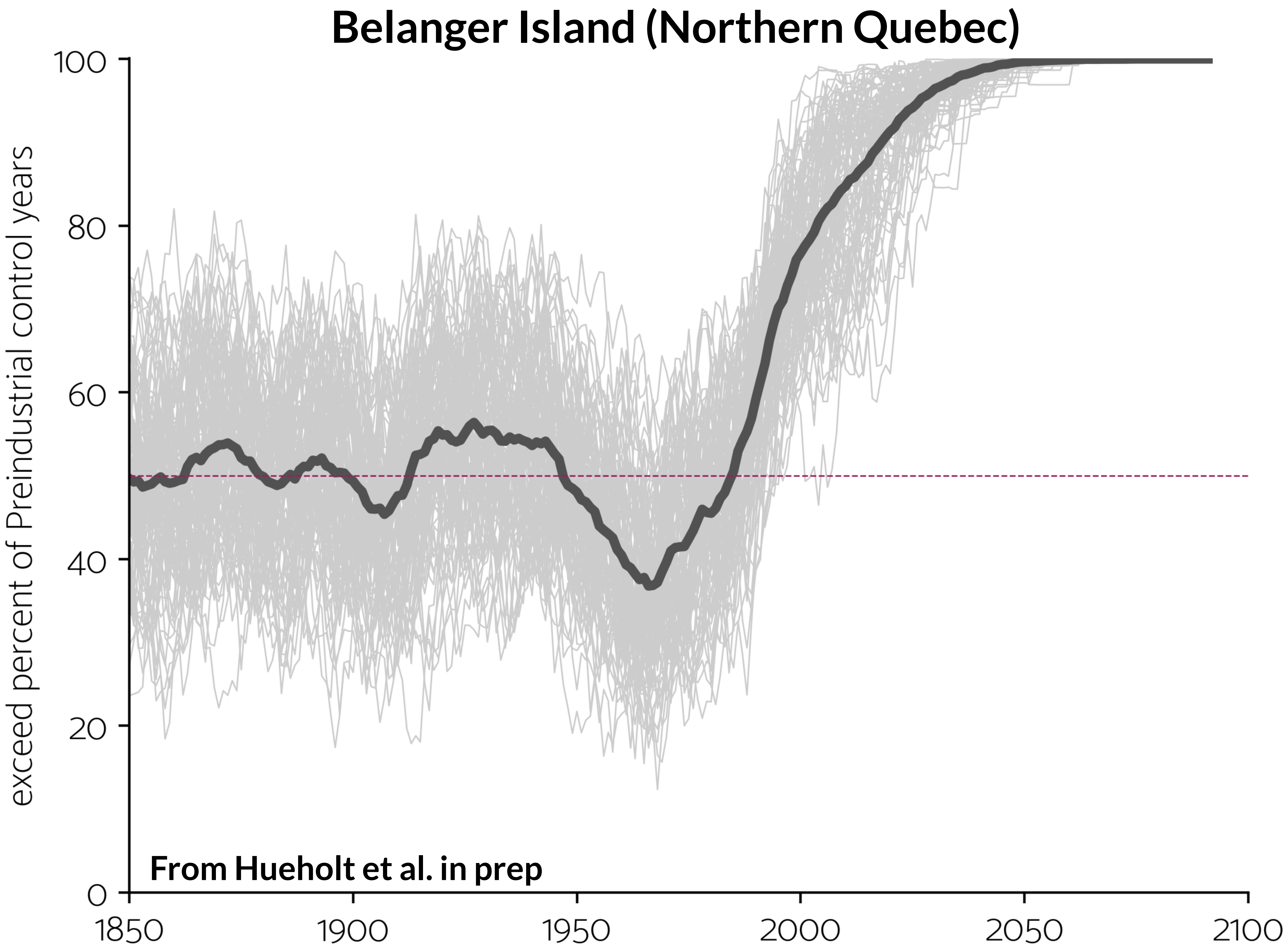

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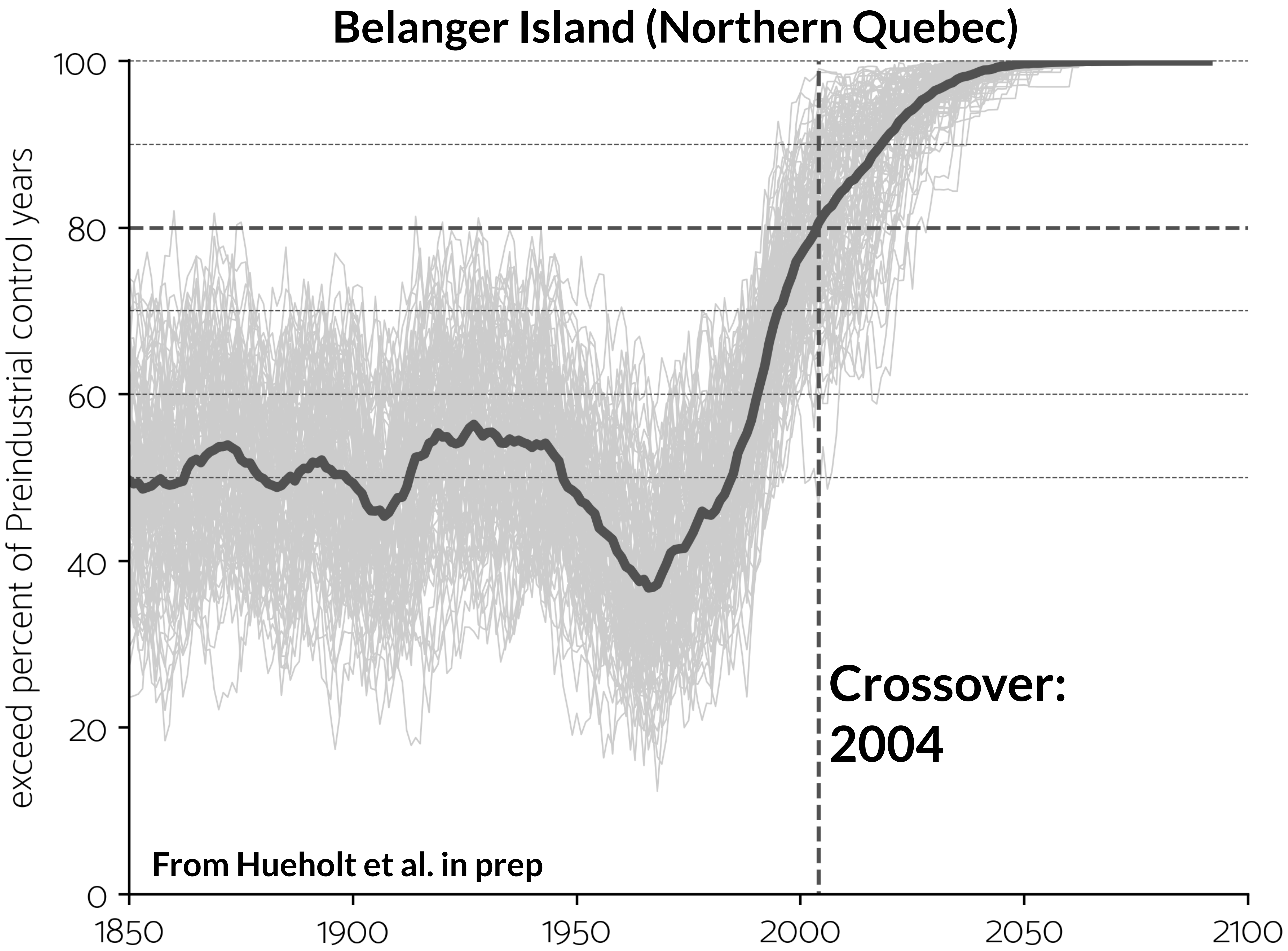
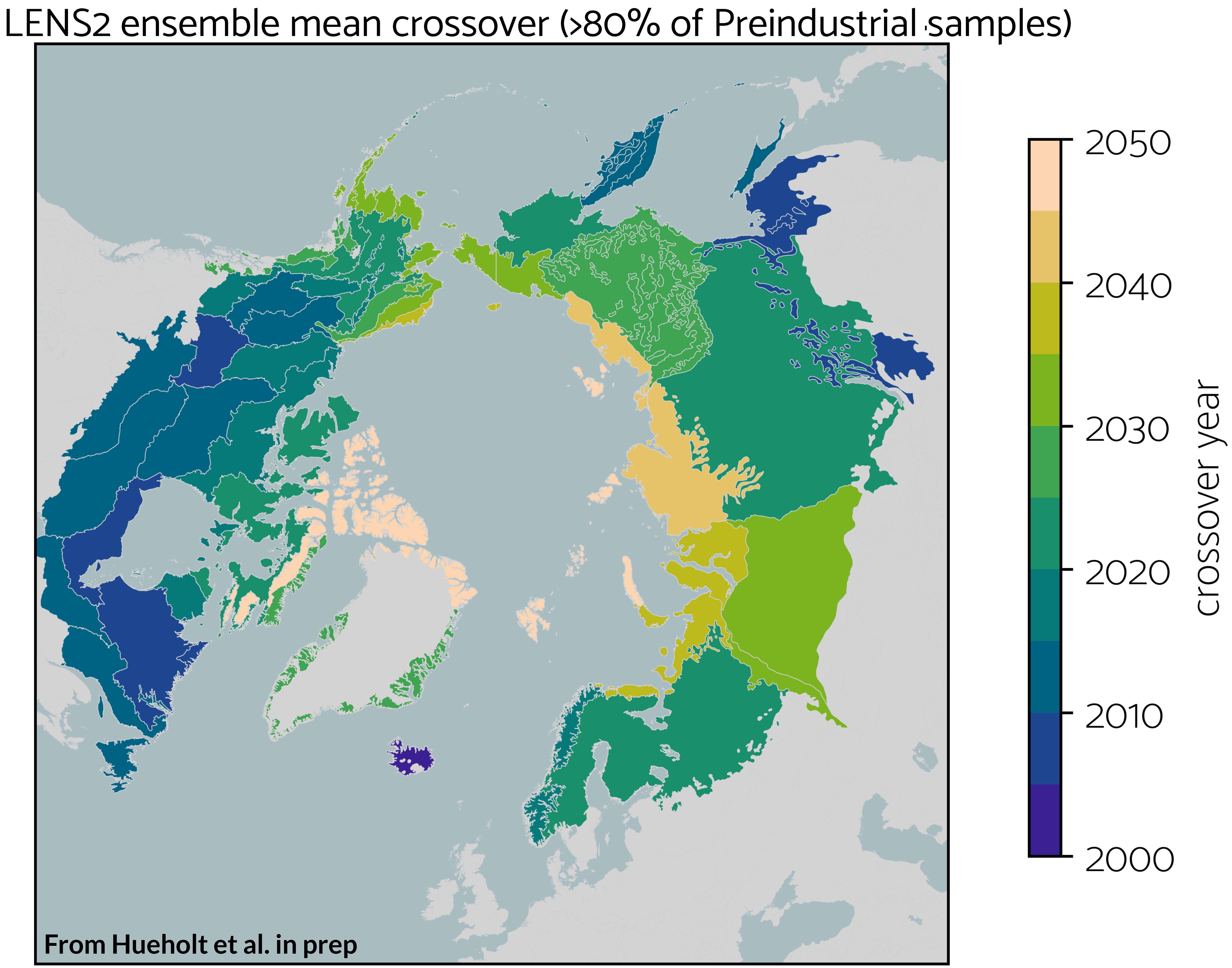


- Count the percent of preindustrial samples exceeded in a year
- When the mean exceeds 80% of the preindustrial, it has clearly emerged from variability

In the ensemble mean, crossover has already occurred in most Arctic ecoregions



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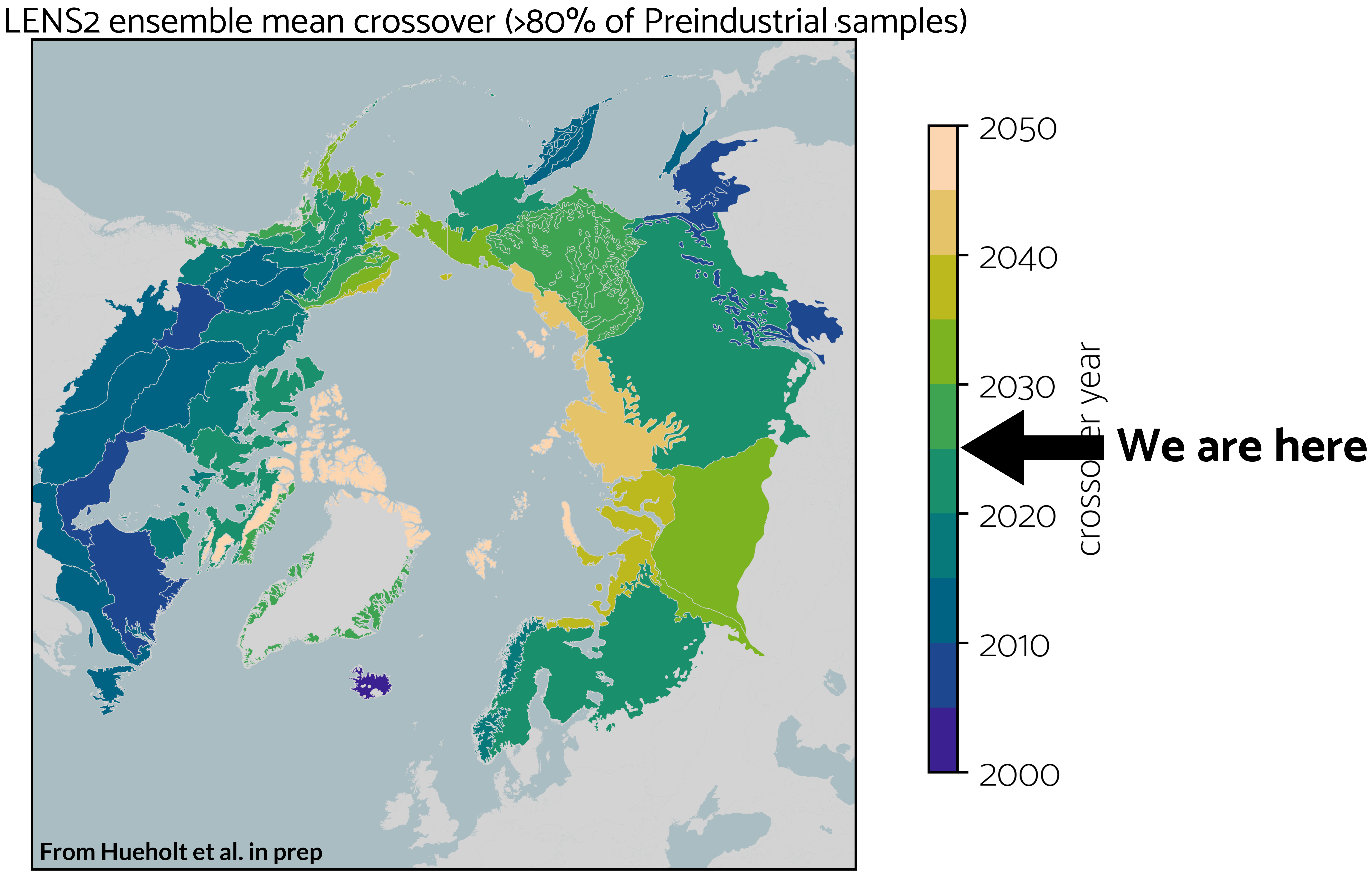
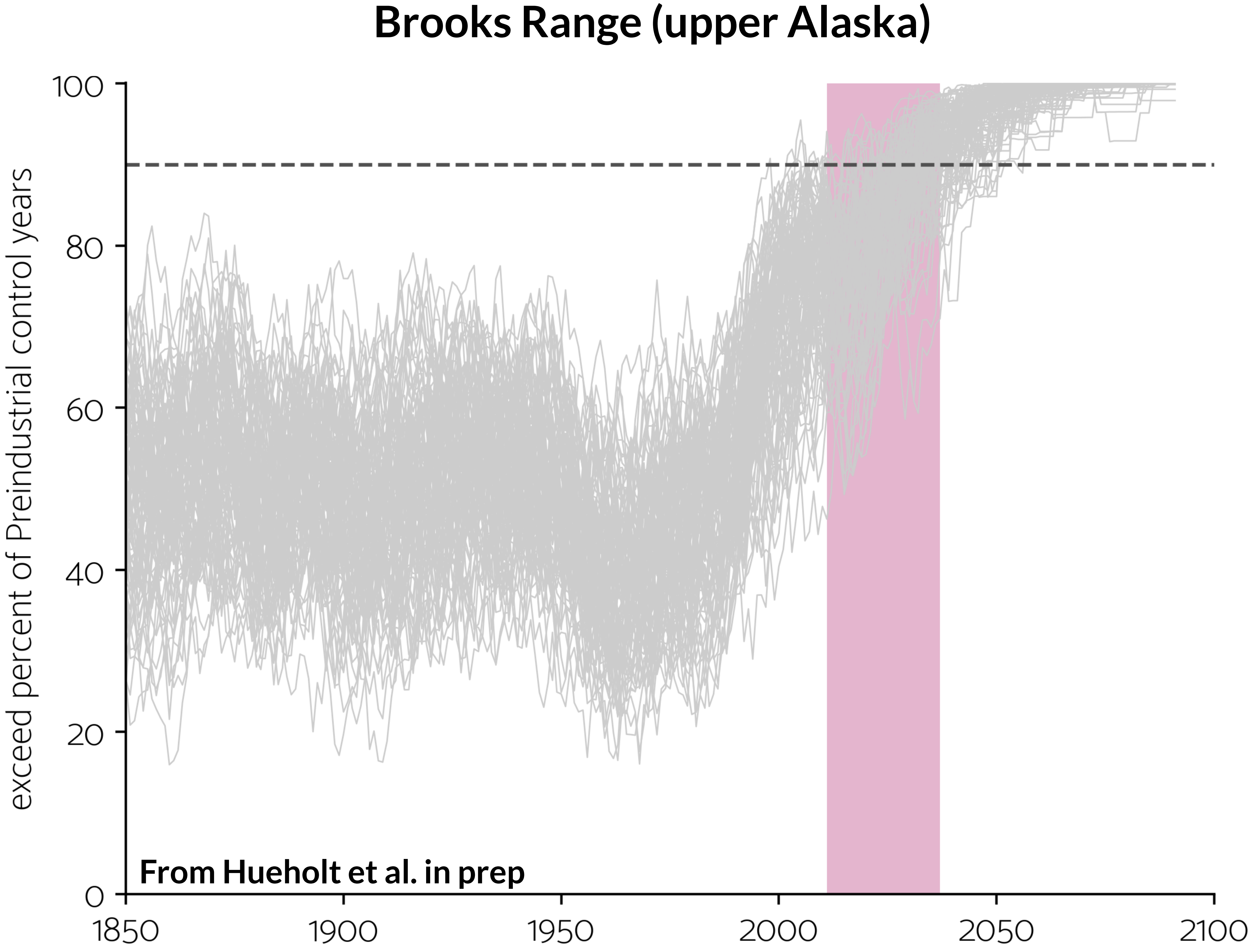
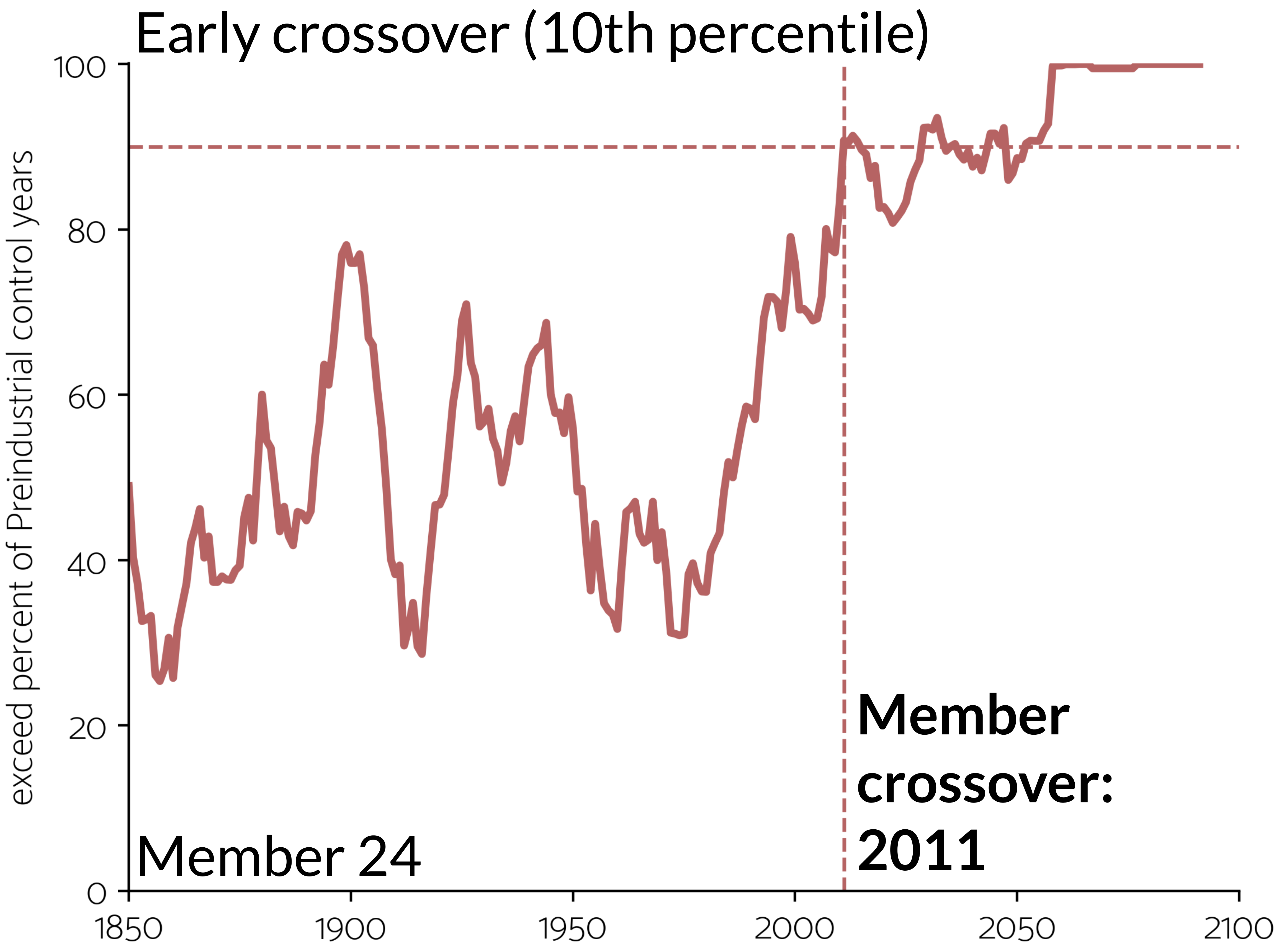


Each ensemble member also has its own crossover time



- May be earlier or later than forced crossover, as influenced by internal variability
- At this site, the 10th to 90th percentile range spans 2011 to 2037

Choose two "storylines" to investigate in more detail



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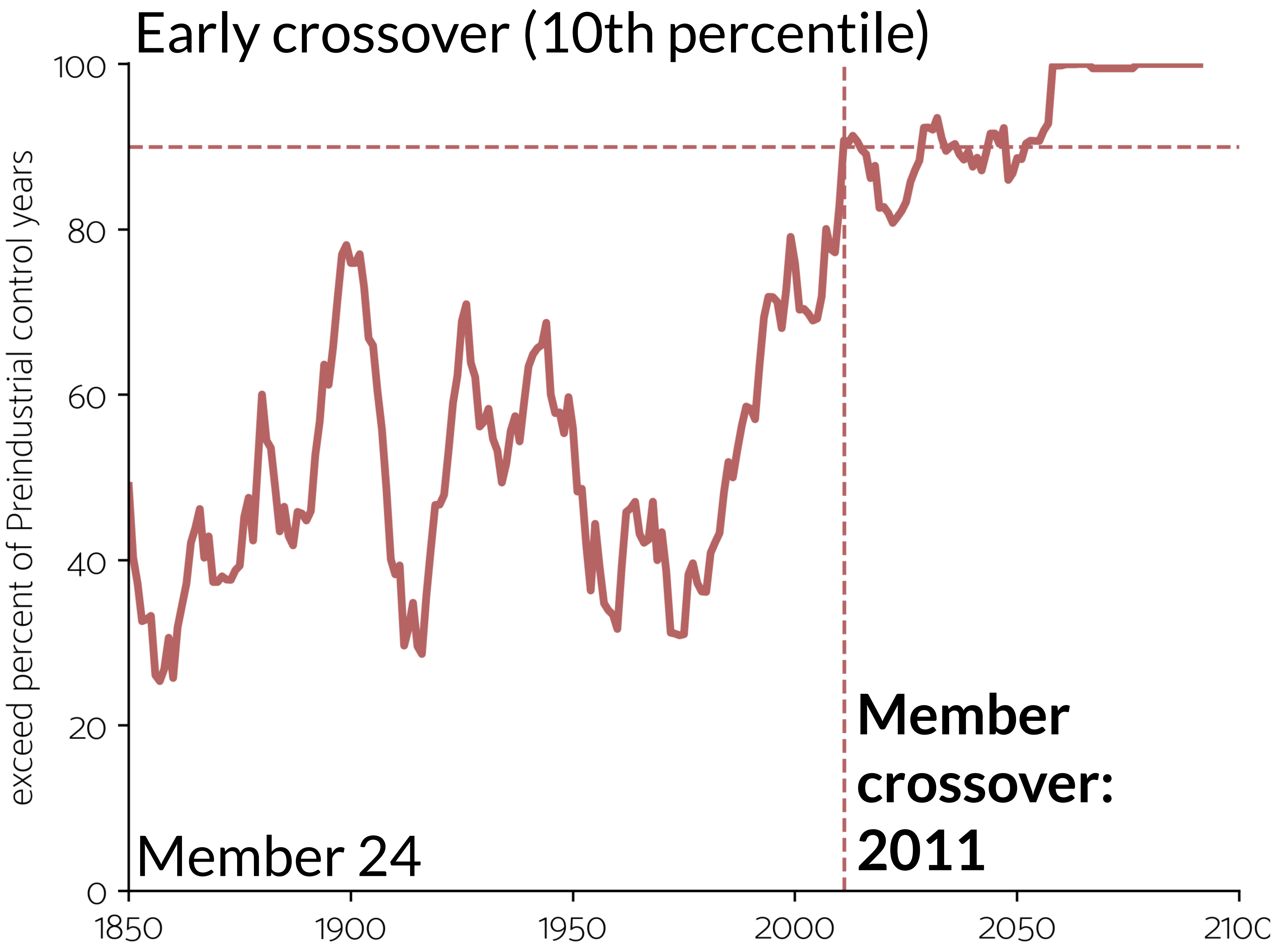

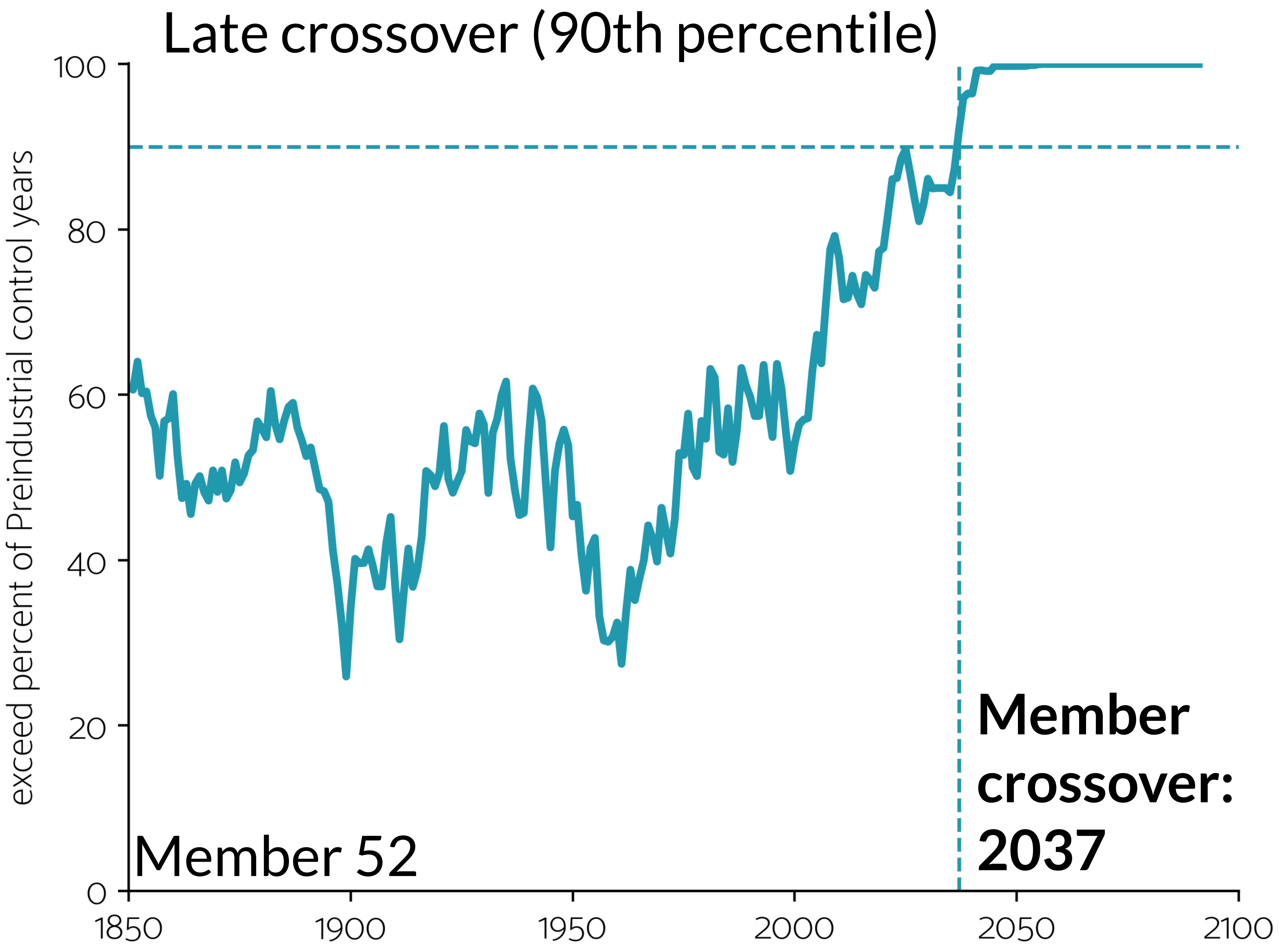

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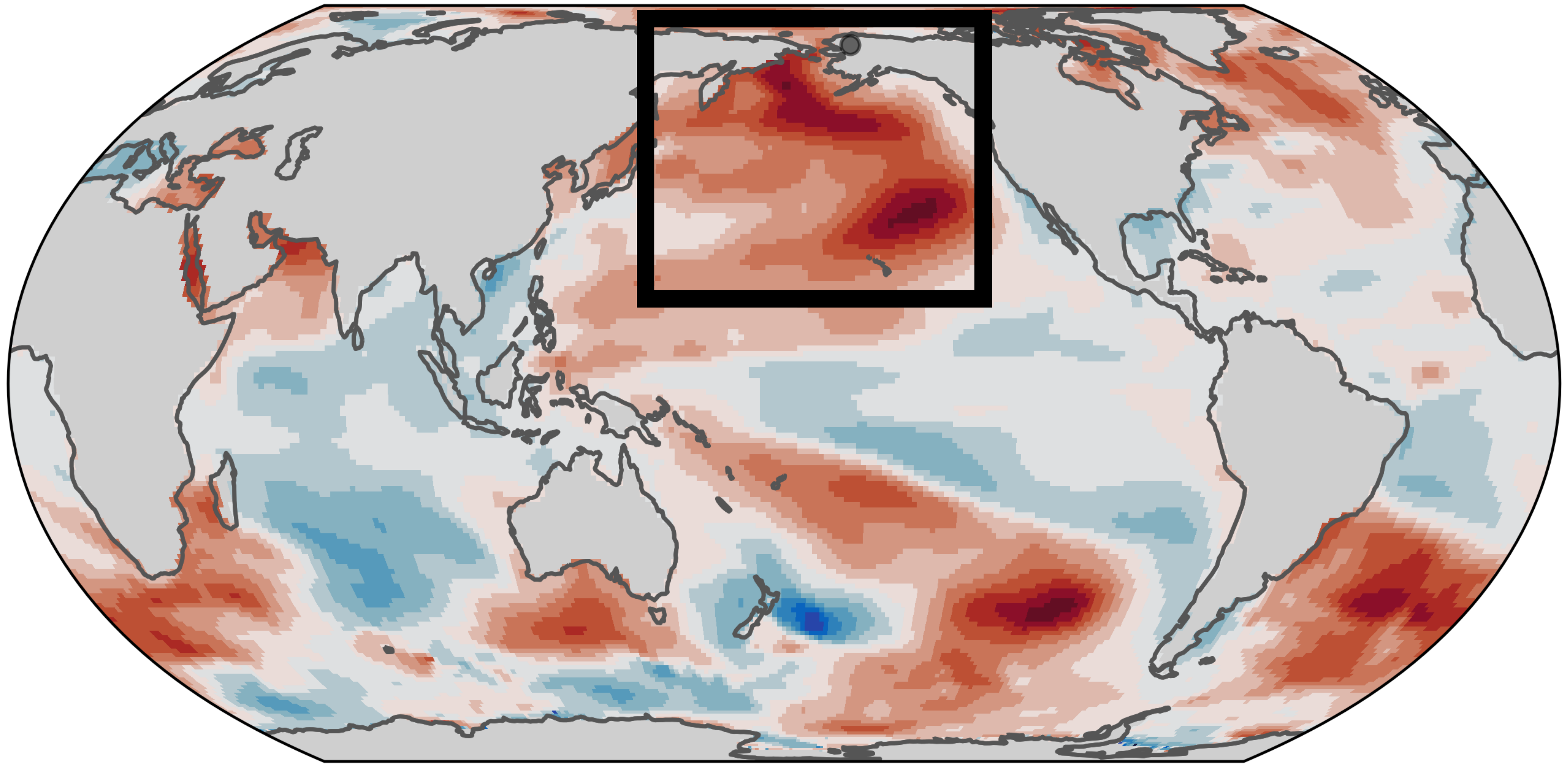
Coupled internal variability is associated with earlier or later crossover

Sea surface temperature anomalies, decade leading to crossover (2002-2011)



Warm North Pacific and Beaufort Sea, early crossover in Brooks Range

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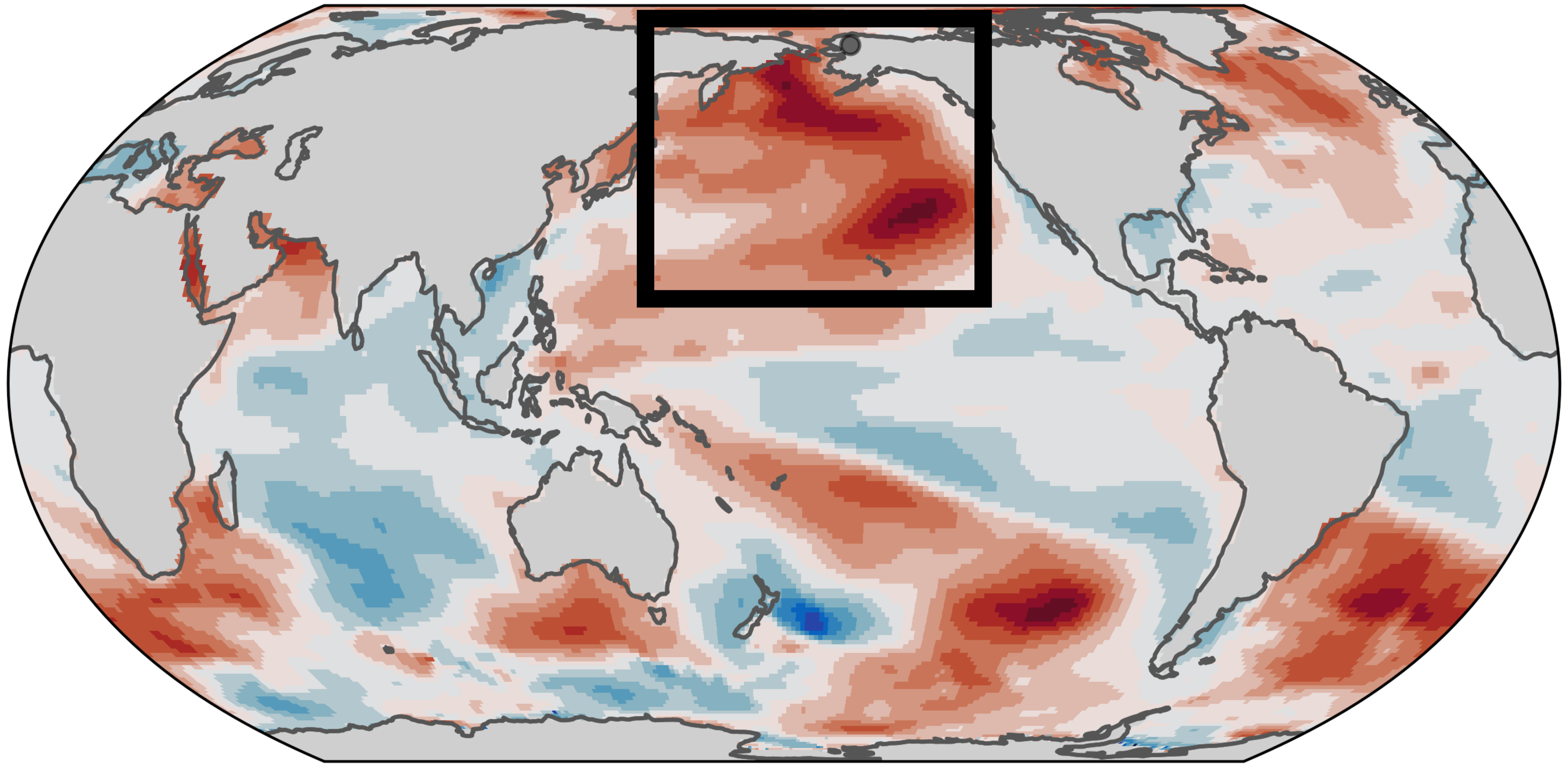
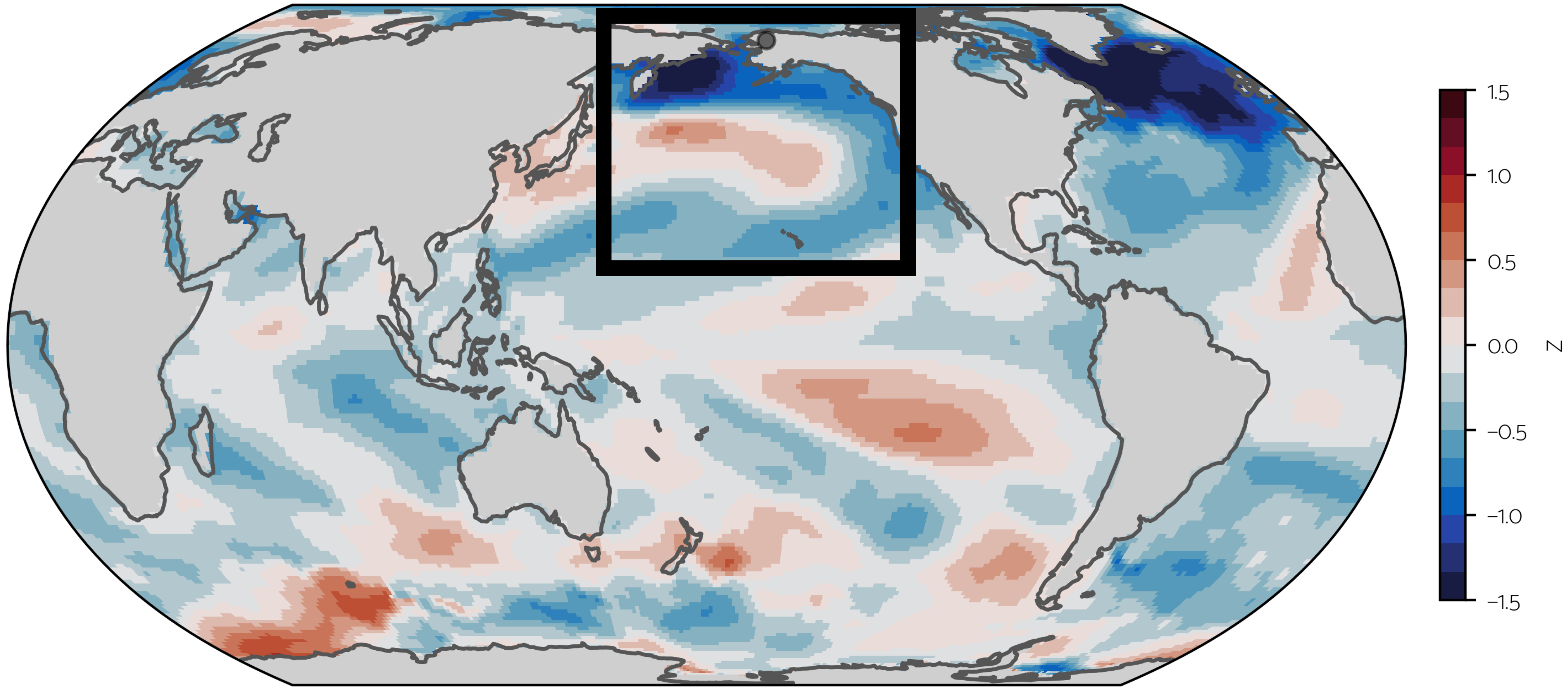


Sea surface temperature anomalies, decade leading to crossover (2026-2037)



Warm North Pacific and Beaufort Sea,
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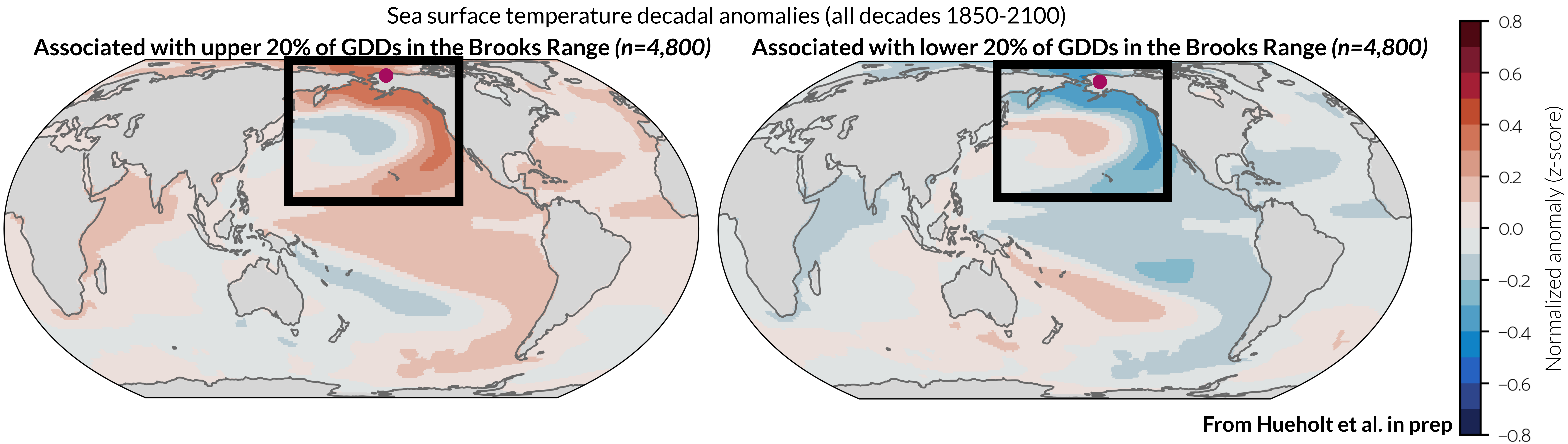
Cold North Pacific and Beaufort Sea,
late crossover in Brooks Range

Internal variability associated with decadal anomalies from all decades



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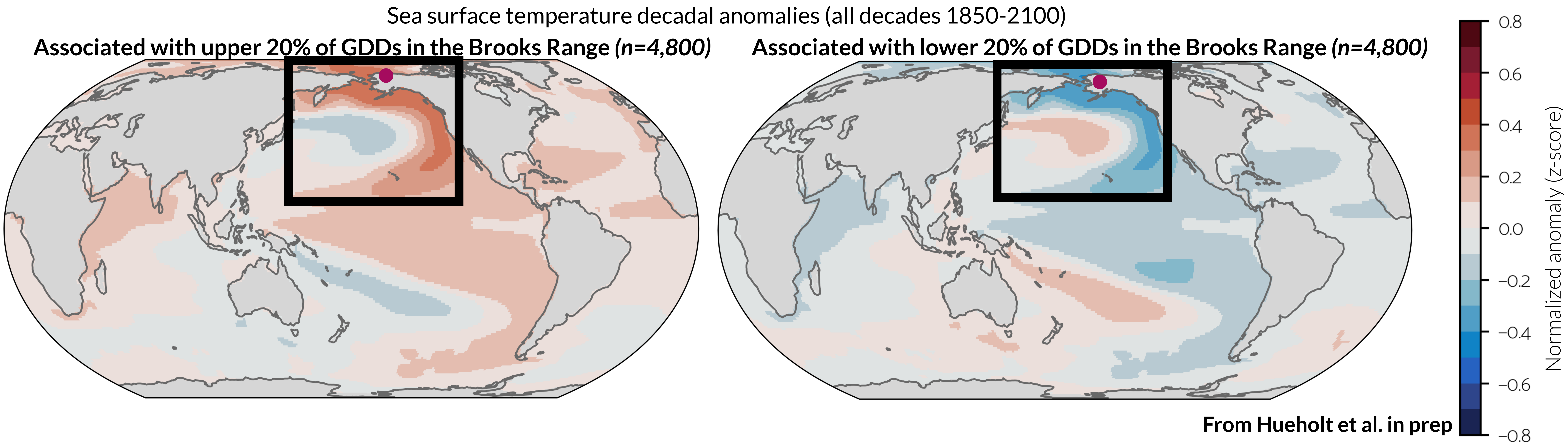
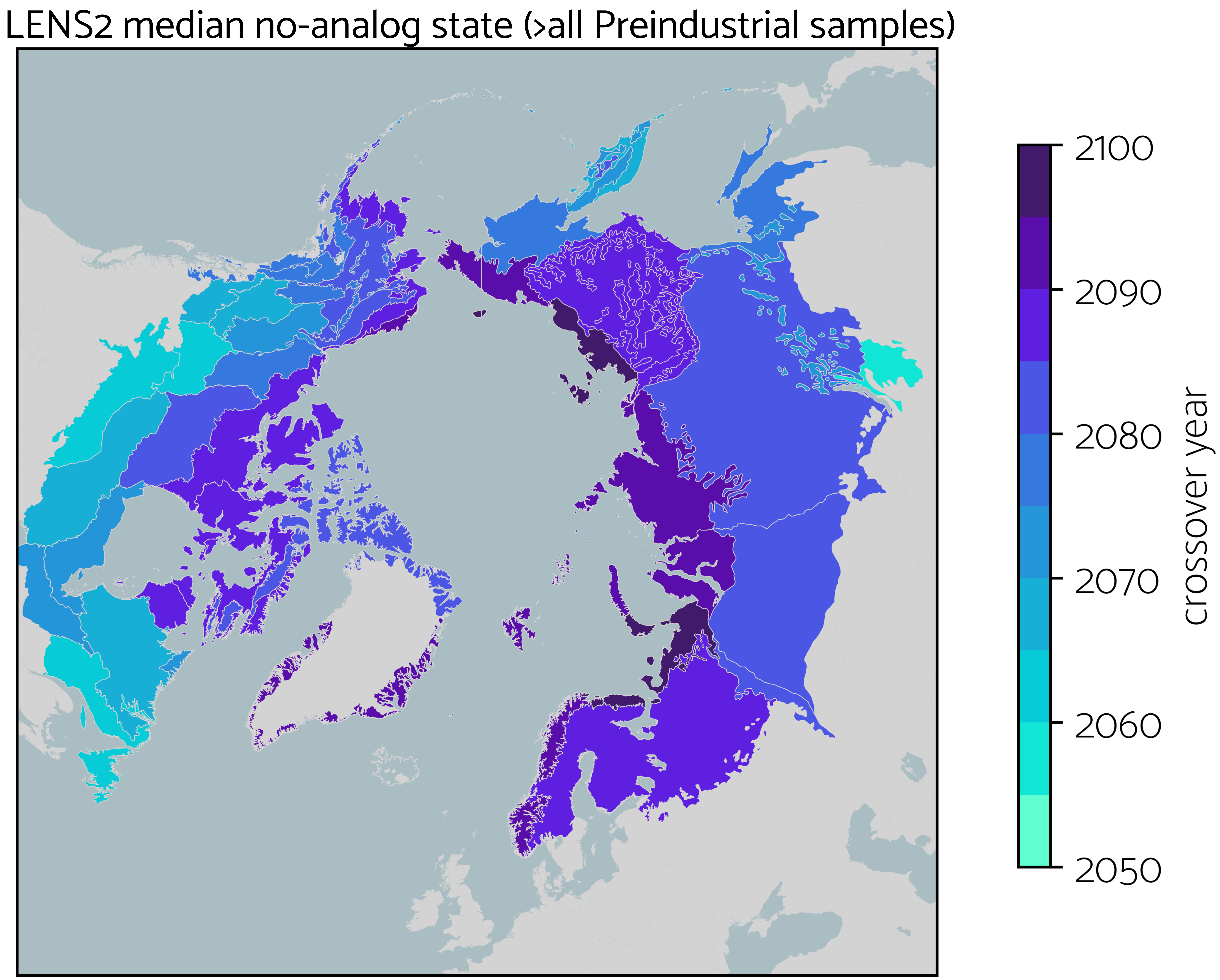


- Sea surface temperature patterns are stable over a large number of samples
- This kind of information could help anticipate future ecosystem change in the real world

No-analog states emerge in mid- to late-century



Summary

- On average, most Arctic ecoregions have already entered a climate regime where the warming trend is dominant (“forced crossover”)
- Storylines illustrate plausible cases of how coupled climate variability may modify this timing (“member crossover”)
- Analysis of full ensemble provides statistical confidence in storylines
- No-analog climate states emerge in mid-to-late 21st century
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Web: hueholt.earth

Footnotes | 1. Rodgers et al. 2021 “Ubiquity of human-induced changes in climate variability”
2. Danabasoglu et al.2020 “The Community Earth System Model Version 2 (CESM2)”
3. Sillmann et al. 2021 “Event-Based Storylines to Address Climate Risk”

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