Climate Uncertainties

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PhD in Economics

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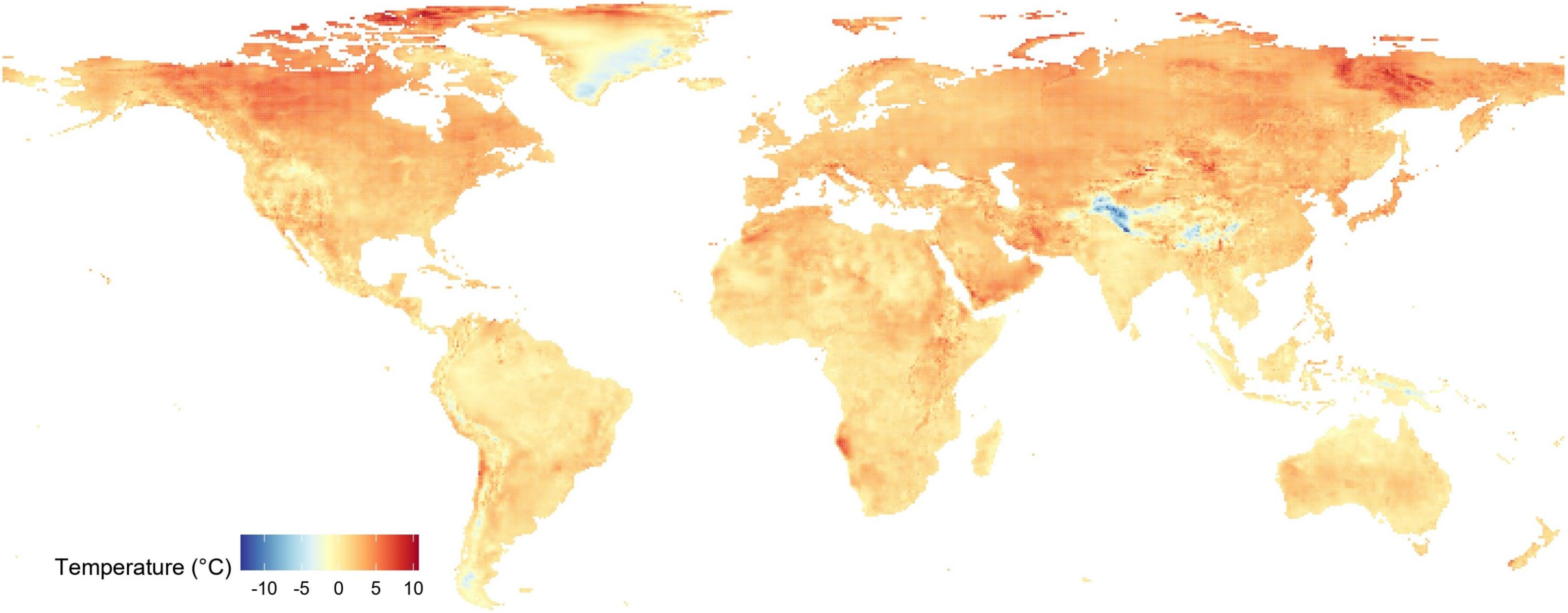
What is the state of the climate today?

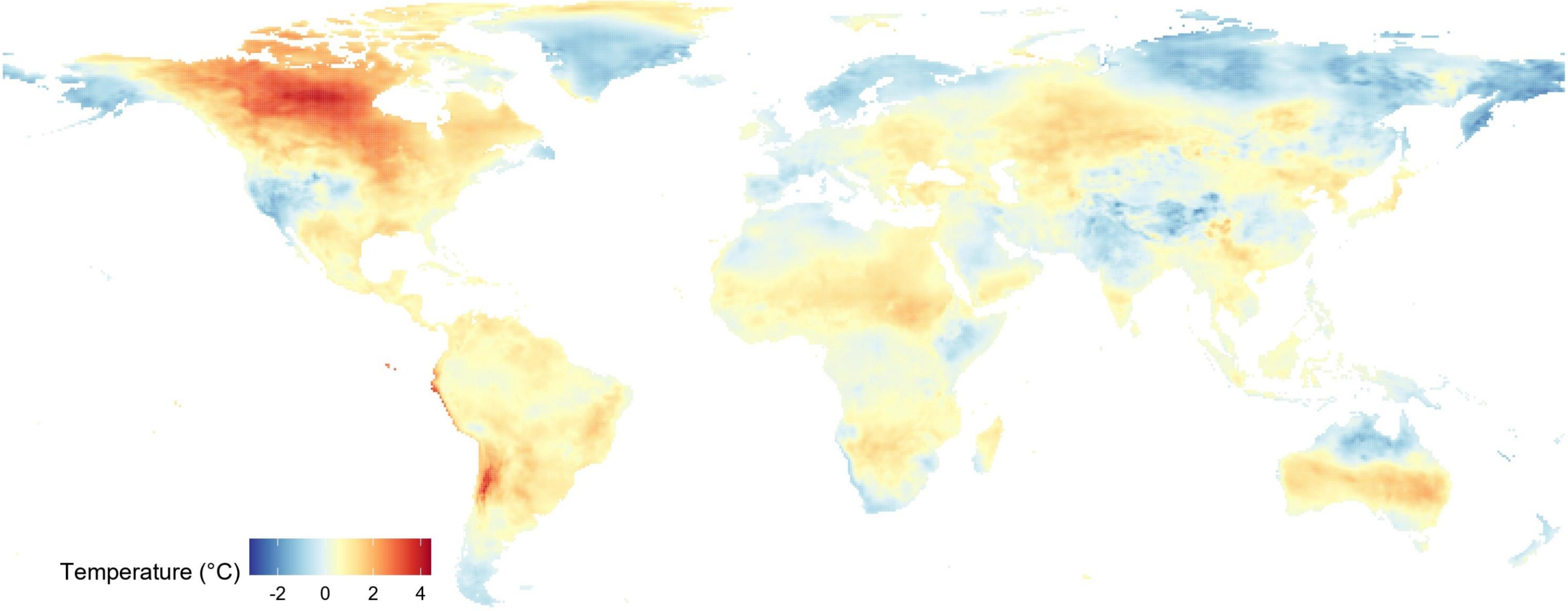
The world has warmed by ~1.2°C. But there is large **spatial heterogeneity**.



Annual average surface temperature increase (in °C) in 2023 (ERA Reanalysis) w.r.t. 1900-1920 (CRU)

What is the state of the climate today?

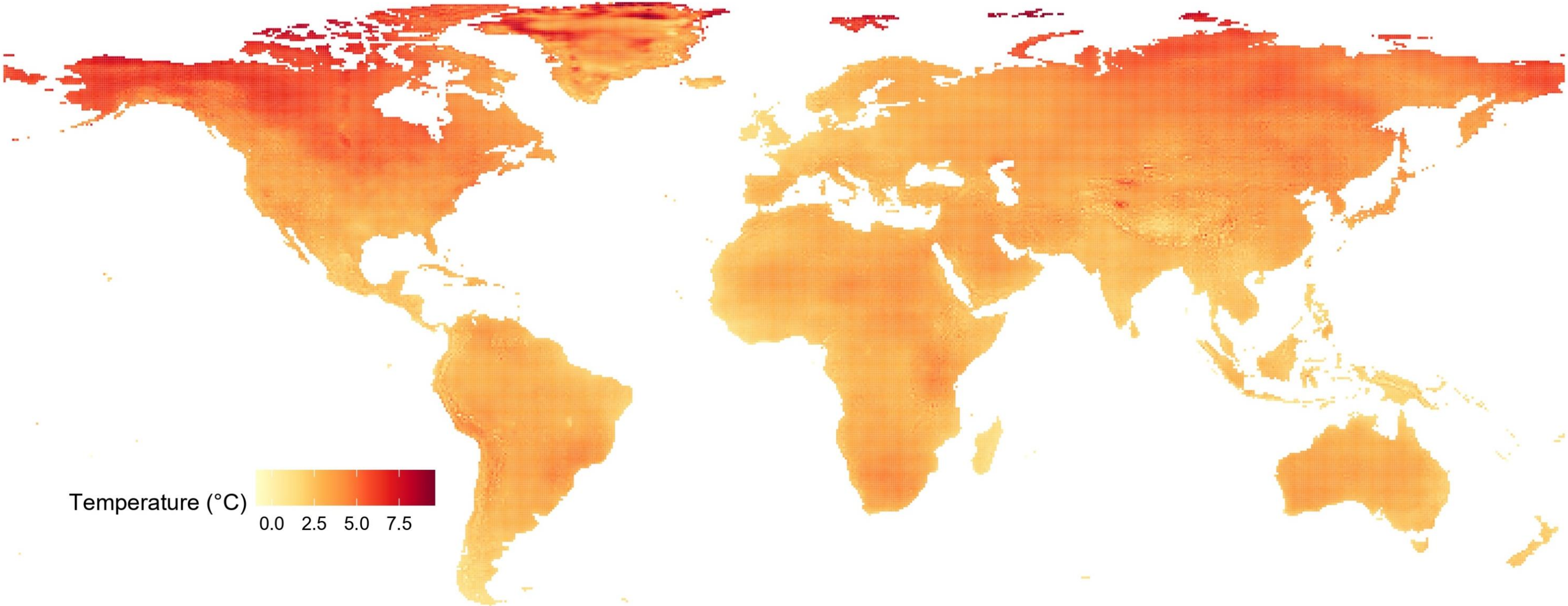
The world has warmed by ~1.2°C. But there is large **temporal** heterogeneity (e.g. inter-annual).



Difference between 2023 and 2022 (in °C) in annual mean surface temperature (ERA Reanalysis)

What could the 2050 climate look like?

Estimating a **synthetic 2050 representative climate** means taking e.g. **10-year mean temperature**

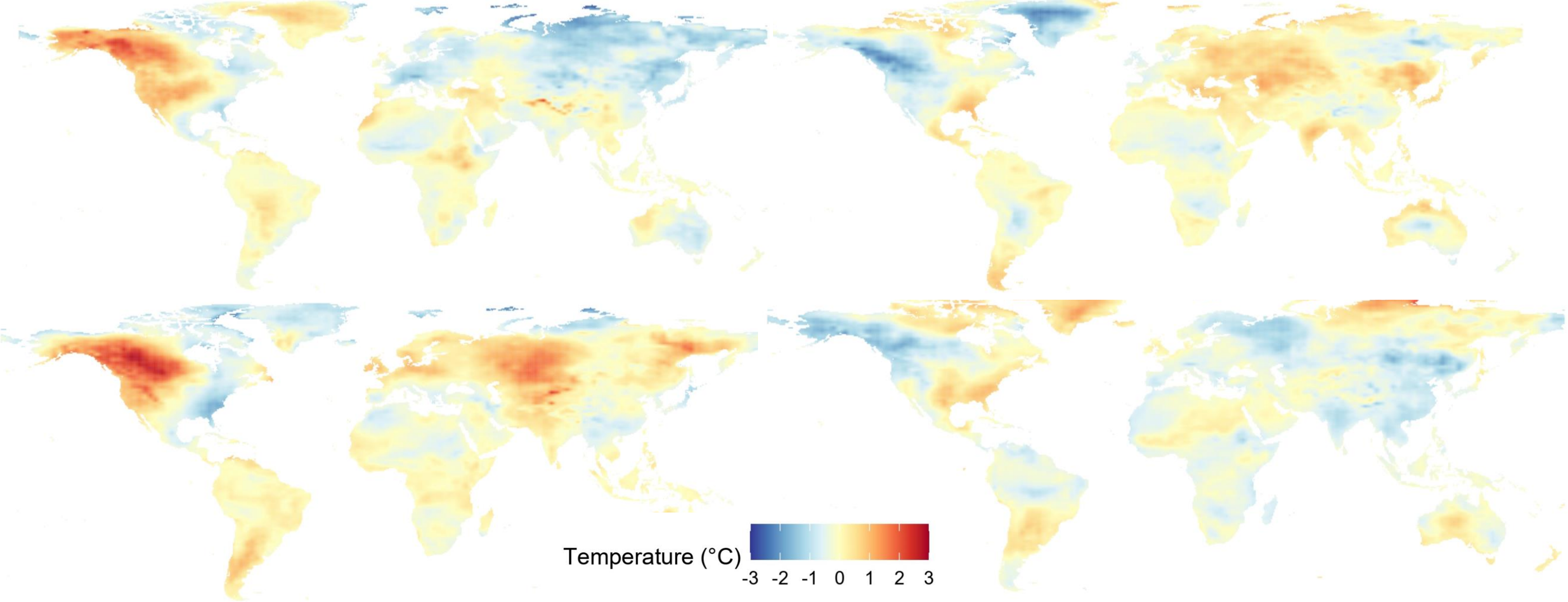


2050 10-year average temperature increase (IPSL-CM6A-LR, « middle-of-the-road » SSP2-4.5, i.e. around +2°C)

Data winsorized at 99.99% for visualization

What could the 2050 climate look like?

But 2050 weather will not be the representative climate, instead **a stochastic weather realizations from the underlying distribution** presented above: there are **multiple possible states of the world**

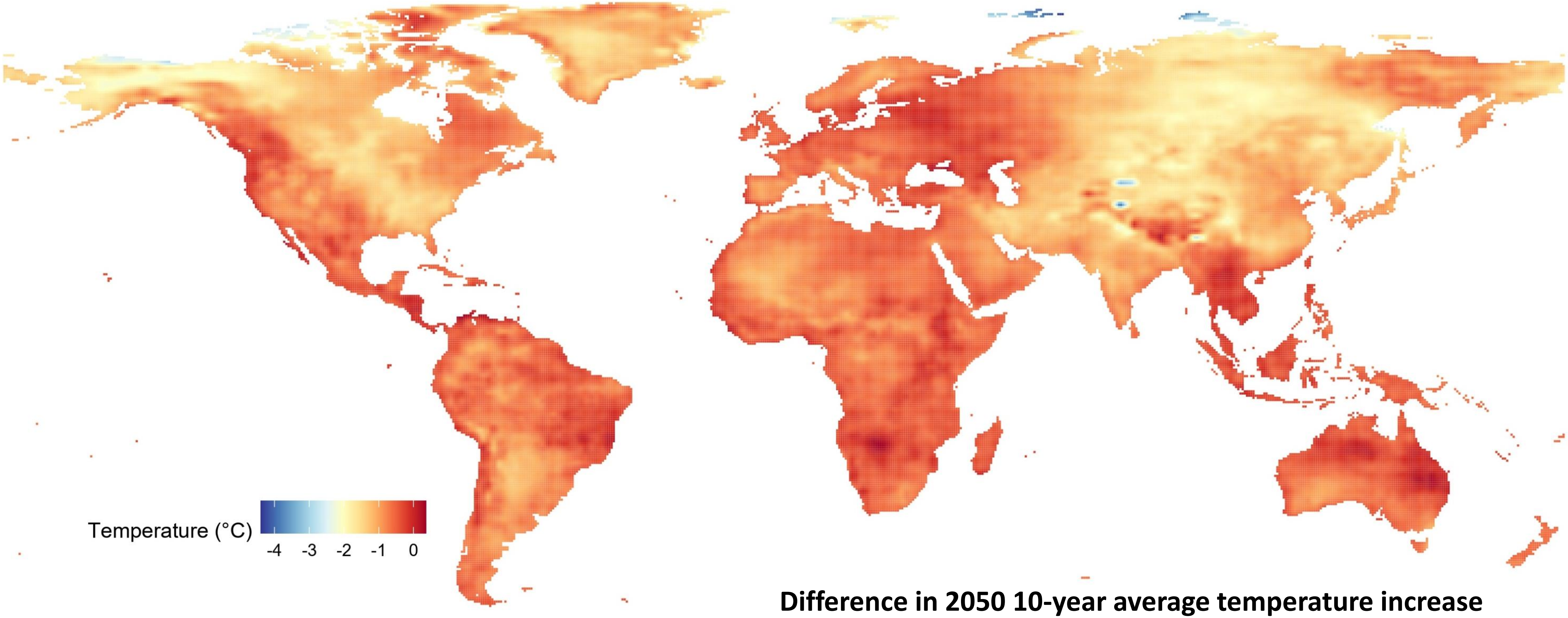


Stochastic weather deviations from 2050 10-year average temperature increase

IPSL-CM6A-LR, « middle-of-the-road » SSP2-4.5, i.e. around +2°C

What could the 2050 climate look like?

The possible distribution of future weather is not unique as there is **scientific uncertainty,** e.g. multiple competing climate models.



Difference in 2050 10-year average temperature increase
IPSL-CM6A-LR vs. GFDL-ESM4, « middle-of-the-road » SSP2-4.5, i.e. around +2°C

I study climate change across these four different dimensions

SPACE	**Different locations over the world** *Spatial aggregation*
TIME	**Different time periods/generations** *Temporal aggregation*
STOCHASTIC RISK	**Different possible states of the world** *Risk modelling*
SCIENTIFIC UNCERTAINTY	**Different possible models of the world** *Model comparability*

And their interactions !

Along each dimension, there are two distinct elements that interact:

	THE OBJECT	**OUR COLLECTIVE ATTITUDE TOWARDS IT**
TIME	Intertemporal fluctuations	Preference for intertemporal smoothing Aversion to intertemporal inequality
SPACE	Spatial heterogeneity	Aversion to intratemporal inequality
RISK	≠ possible states of the world	Aversion to risk
SCIENTIFIC UNCERTAINTY	≠ possible models of the world	Aversion to scientific uncertainty

To me, taking climate uncertainties seriously across four dimensions involves **working in two complementary directions**

POSITIVE APPROACH
How **do** these uncertainties affect our projections of future climate impacts?

NORMATIVE APPROACH
How **should** these uncertainties affect social choice?

THIS PHD THESIS

Chapter 1 - "Optimal climate policy under tipping risk and temporal risk aversion"
With Nicolas Taconet (CIRED, PIK & DG Trésor) and Céline Guivarch (CIRED)

Chapter 2 – "The need for regulation of climate subsystems"
With Céline Guivarch (CIRED)

Chapter 3 – "Climate shift uncertainty and economic damages"
With Manuel Linsenmeier (Princeton, HMEI) and Gernot Wagner (Columbia, GSB)

Chapter 4 – "The Biophysical Channels of Climate Impacts"

DIMENSION	Chapter 1	Chapter 2	Chapter 3	Chapter 4
Time	■	■		■
Space			■	■
Risk	■	■		
Scientific Uncertainty		■	■	

APPROACH	Chapter 1	Chapter 2	Chapter 3	Chapter 4
Normative	■	■		
Positive			■	■

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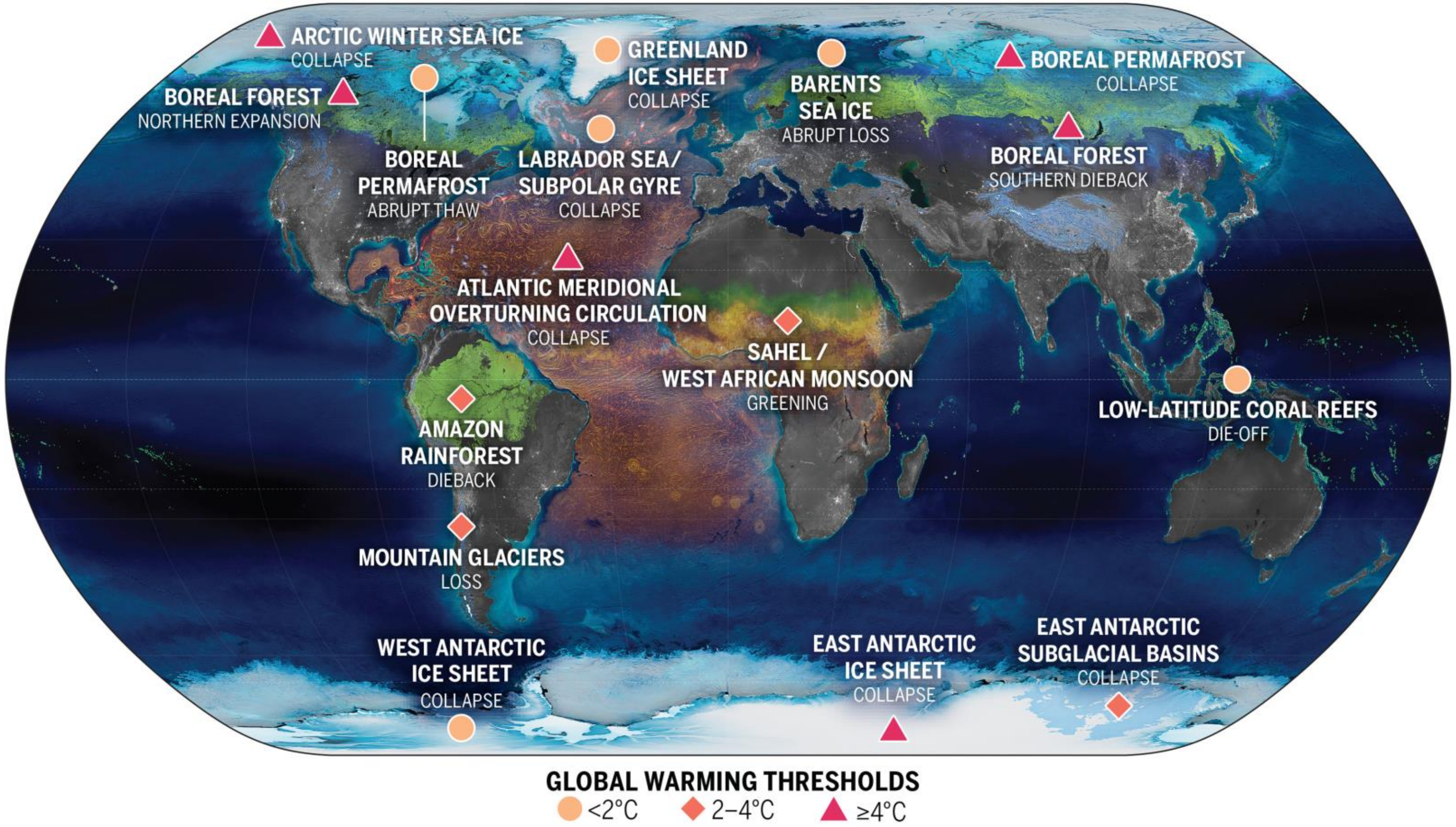
DIMENSION	Chapter 1
Time	■
Space	
Risk	■
Scientific Uncertainty	

APPROACH	Chapter 1
Normative	■
Positive	

CHAPTER 1

MOTIVATION: How to evaluate **irreversible** catastrophic social situations? What should **society's attitude** be towards those risks? For instance, **climate tipping risks**.



Climate tipping elements - illustration taken from D. Armstrong Mc Kay et al., *Science* (2022)

CHAPTER 1

MOTIVATION: How to evaluate irreversible catastrophic social situations? What should society's attitude be towards those risks? For instance, climate tipping risks.

QUESTION: should society put **more weights** on these situations (i.e. more **temporal risk aversion**)?

RESEARCH GAP: under standard expected utility, society is assumed to be temporally risk-neutral, i.e. does not pure more weights on situations with large aggregate intertemporal risk.

Key references:
Bommier, Lanz, Zuber, 2015, *Journal of Environmental Economics and Management*
Bommier, Kochov, Le Grand, 2017, *Econometrica*

CHAPTER 1

MOTIVATION: How to evaluate irreversible catastrophic social situations? What should society's attitude be towards those risks? For instance, climate tipping risks.

QUESTION: should society put more weights on these situations (i.e. more temporal risk aversion)?

RESEARCH GAP: under standard expected utility, society is assumed to be temporally risk-neutral, i.e. does not pure more weights on situations with large aggregate intertemporal risk.

METHOD:
1. A **risk-sensitive social choice** criterion allowing temporal risk aversion
2. Quantification with a dynamic stochastic climate-economy model

RESULTS: The price on carbon emissions **increases sharply** with temporal risk aversion, e.g. a 30% increase in carbon price for a 10% irreversible increase in climate damage to productivity.

IMPLICATIONS: if society believes it faces large risks, then we might prefer to put more weights on these possible outcomes. If not, then we can stick to expected utility (and temporal risk neutrality).

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DIMENSION	Chapter 2
Time	■
Space	
Risk	■
Scientific Uncertainty	■

APPROACH	Chapter 2
Normative	■
Positive	

CHAPTER 2

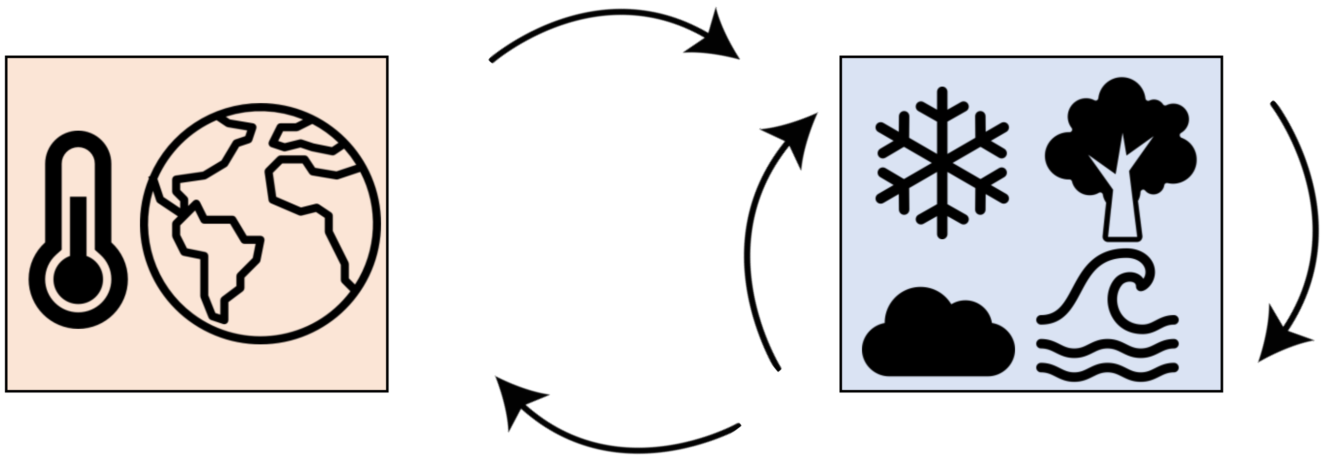
MOTIVATION: analyze and quantify how climate dynamics matter for economic policy.

QUESTION: how to evaluate **climate subsystems**?

We study climate subsystems with three properties:

1. Climate subsystems impact climate change.
2. Climate change impacts climate subsystems.
3. Climate subsystems are not entirely determined by climate change.

Examples: tipping elements, large systems without tipping property like some rainforests.



CHAPTER 2

MOTIVATION: analyze and quantify how climate dynamics matter for economic policy.

QUESTION: how to evaluate climate subsystems?

RESEARCH GAP: modelling of climate subsystems for economic policy either **deterministic** or without explicit calibration of **geophysical dynamics**.

Key references:
Cai & Lontzek, 2019, *Journal of Political Economy*
Dietz *et al.*, 2021, *Proceedings of the National Academy of Sciences*

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MOTIVATION: analyze and quantify how climate dynamics matter for economic policy.

QUESTION: how to evaluate climate subsystems?

RESEARCH GAP: modelling of climate subsystems for economic policy either **deterministic** or without explicit calibration of **geophysical dynamics**.

METHOD:

1. Analytics. Identify the impacts of climate subsystems on **optimal global policy & subsystem management** with value function decomposition.
2. Numerics. Quantify these impacts with **dynamic stochastic climate-economy model** & explicit stylized calibrated **geophysical dynamics** of an endogenous climate subsystem: the Amazon rainforest.

Analytical results

Climate subsystems influence global climate policy via 3 channels

1. Climate subsystems have a **direct feedback** on climate (↑ or ↓ global & regional temp.).

2. Climate change perturbs climate subsystems, impacting their **long-term survival**.

3. Climate subsystems have different **insurance value** — indeed, depending on the state of the world where climate damages ↑ or ↓ global and regional temp., they increase or decrease aggregate climate risk and should be evaluated accordingly.

Tipping element	Warming threshold	Sign of impacts
Greenland & West Antarctic Ice Sheets	<2°C	+
Labrador-Irminger Seas / SPG Convection	<2°C	-
Amazon rainforest	2-4°C	+
Atlantic Meridional Overturning Circulation	>4°C	-

Climate tipping elements – data taken from D. Armstrong Mc Kay et al., *Science* (2022)

CHAPTER 2

Analytical results

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Climate subsystems' management should include the dynamics of the system

SCDS: Social Cost of the Dynamic System. It is the intertemporal social cost of a marginal decrease in the subsystem's state today, which captures the extent to which the subsystem's ability to self-perpetuate changes with a marginal change in its state.

CHAPTER 2

Numerical results

3 key components for the calibration

1. Amazon rainforest is a **state variable**, with explicit stylized geophysical dynamics.

2. Amazon rainforest has a tipping risk that is an **emerging property** of the dynamic system rather than an *ad hoc* probability of dieback.

3. We provide a stylized calibration of the Amazon dynamics, that go **beyond direct impacts** from deforestation (i.e. degradation, stochastic droughts, vegetation-rainfall feedbacks).

3 key numerical results

1. Amazon' endogenous dynamics implies a **15% risk premium** on the global carbon price.

2. Amazon' endogenous dynamics implies a **SCDS that is worth 16% of the carbon price**.

3. These results imply that a **24% increase in the marginal value of a tCO_2 stored** in the rainforest should be applied in local cost-benefit analysis of deforestation.

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2. Numerics. Quantify these impacts with dynamic stochastic climate-economy model & explicit stylized calibrated geophysical dynamics of an endogenous climate subsystem: the Amazon rainforest.

IMPLICATIONS: climate subsystems should be studied in *stochastic* frameworks with *geophysical* dynamics because this modeling approach matters *qualitatively* and *quantitatively.*

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DIMENSION	Chapter 3
Time	
Space	■
Risk	
Scientific Uncertainty	■

APPROACH	Chapter 3
Normative	
Positive	■

CHAPTER 3

MOTIVATION: understanding how future climate damages may unfold across time and space.

QUESTION: how **aggregating over space & time** bias climate damage estimates?

RESEARCH GAP: most models evaluated at the same scale (***global annual*** **mean temperature**).

Key reference:
Desmet & Rossi-Hansberg, 2024, *Annual Review of Economics*

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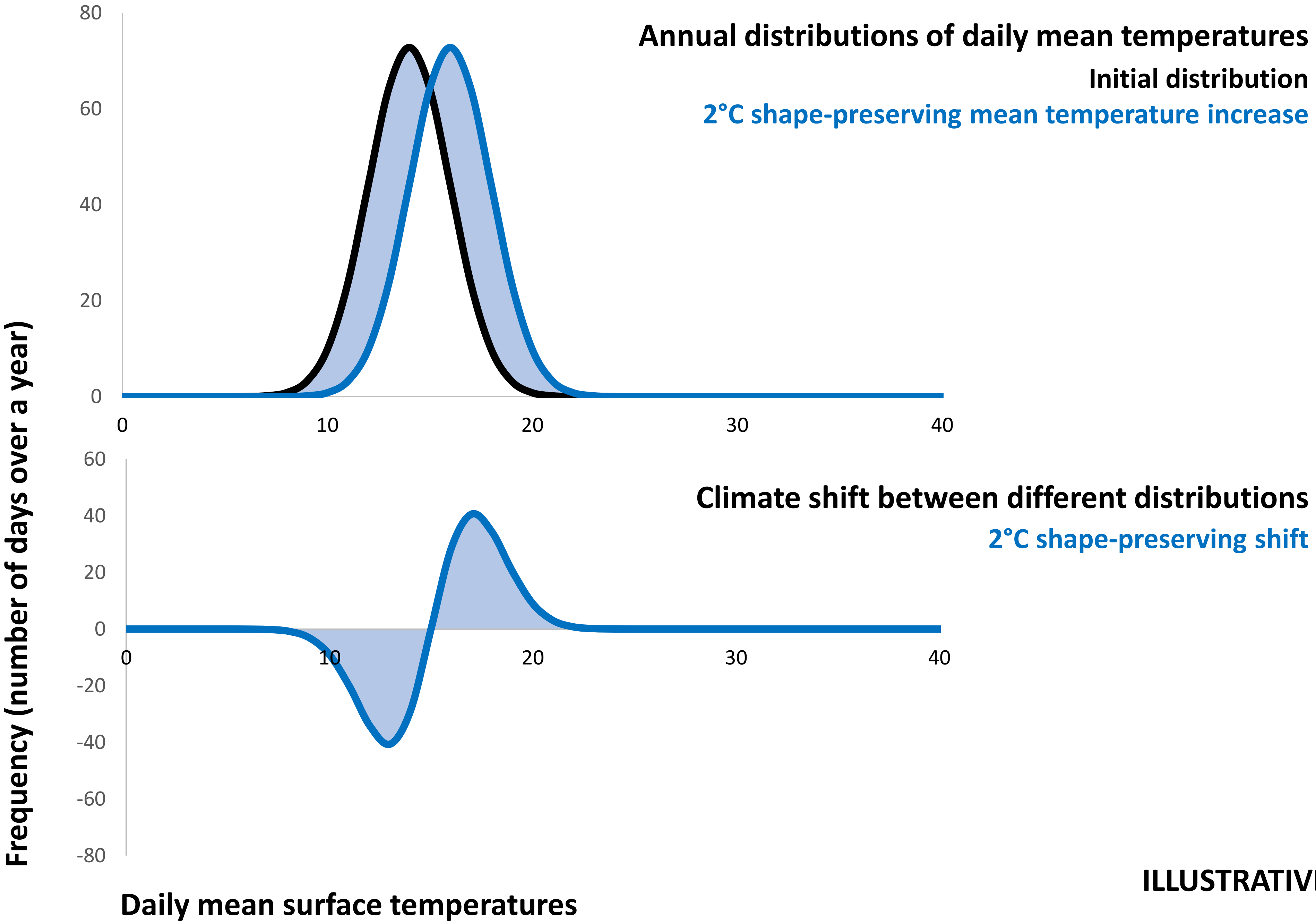
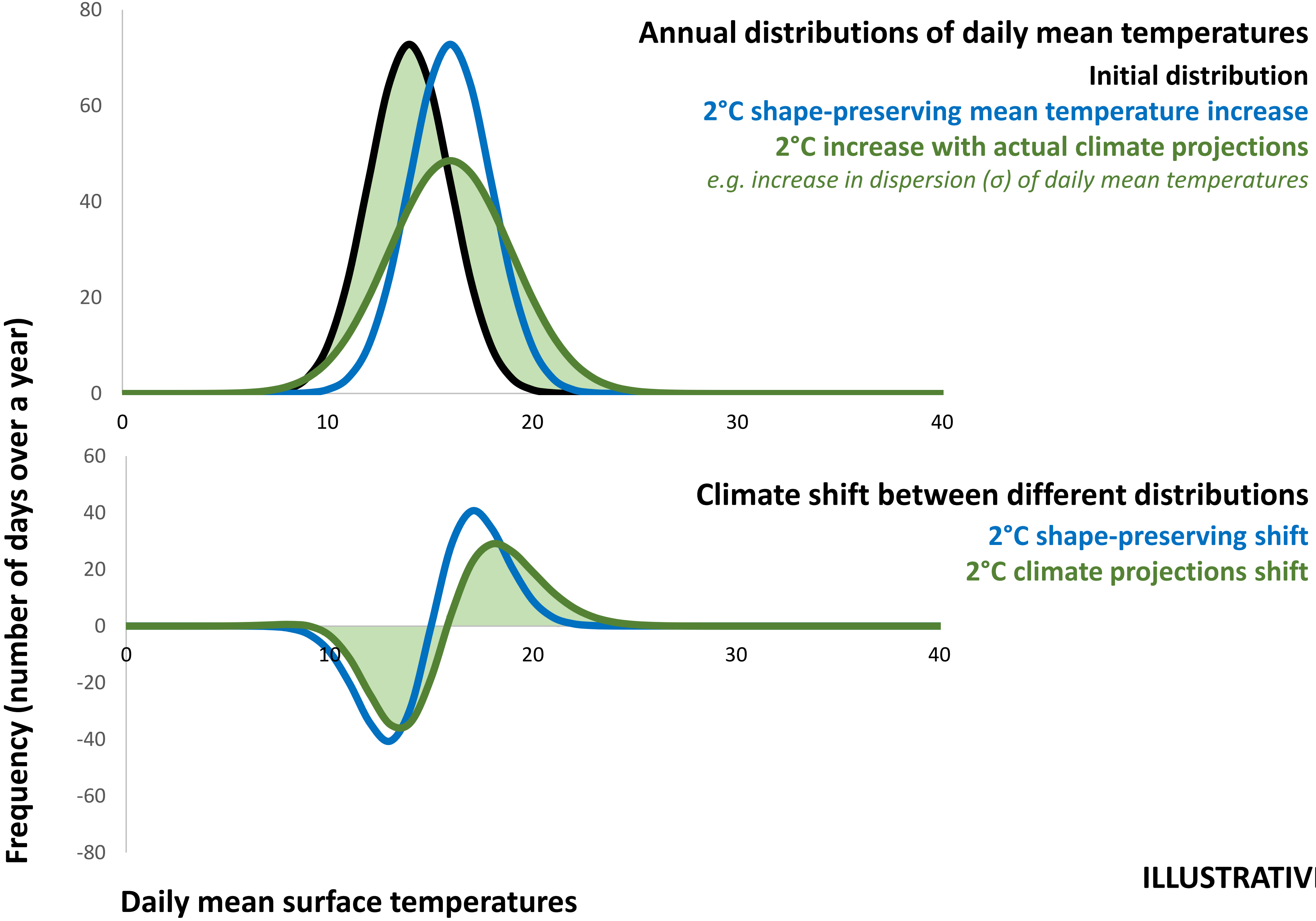
METHOD: we combine at the **regional** scale
1. Warming patterns from climate projections of annual distribution of **daily mean temperatures**.
2. Damage patterns empirically estimated with non-linear damage functions.



ILLUSTRATIVE

CHAPTER 3



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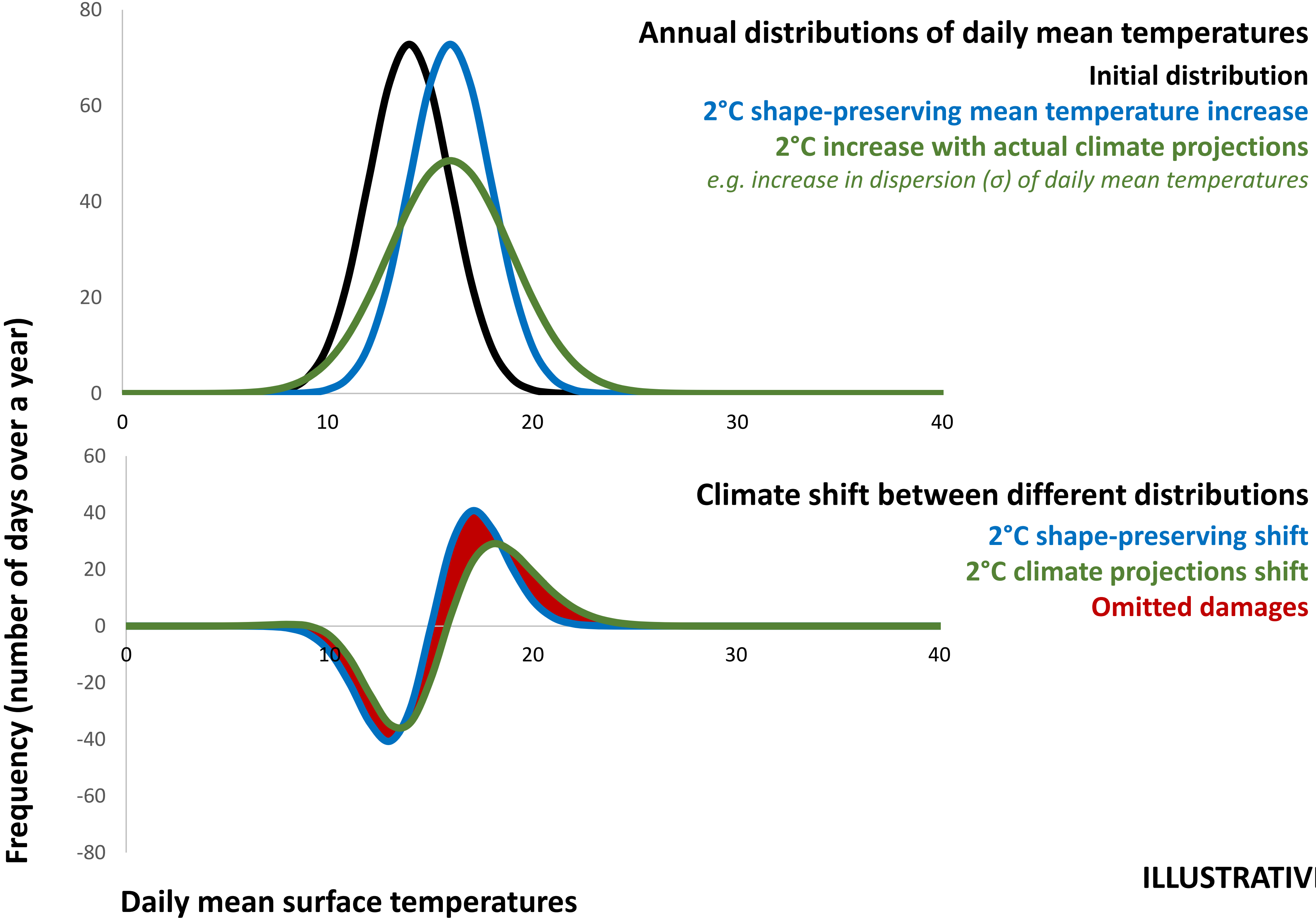

ILLUSTRATIVE

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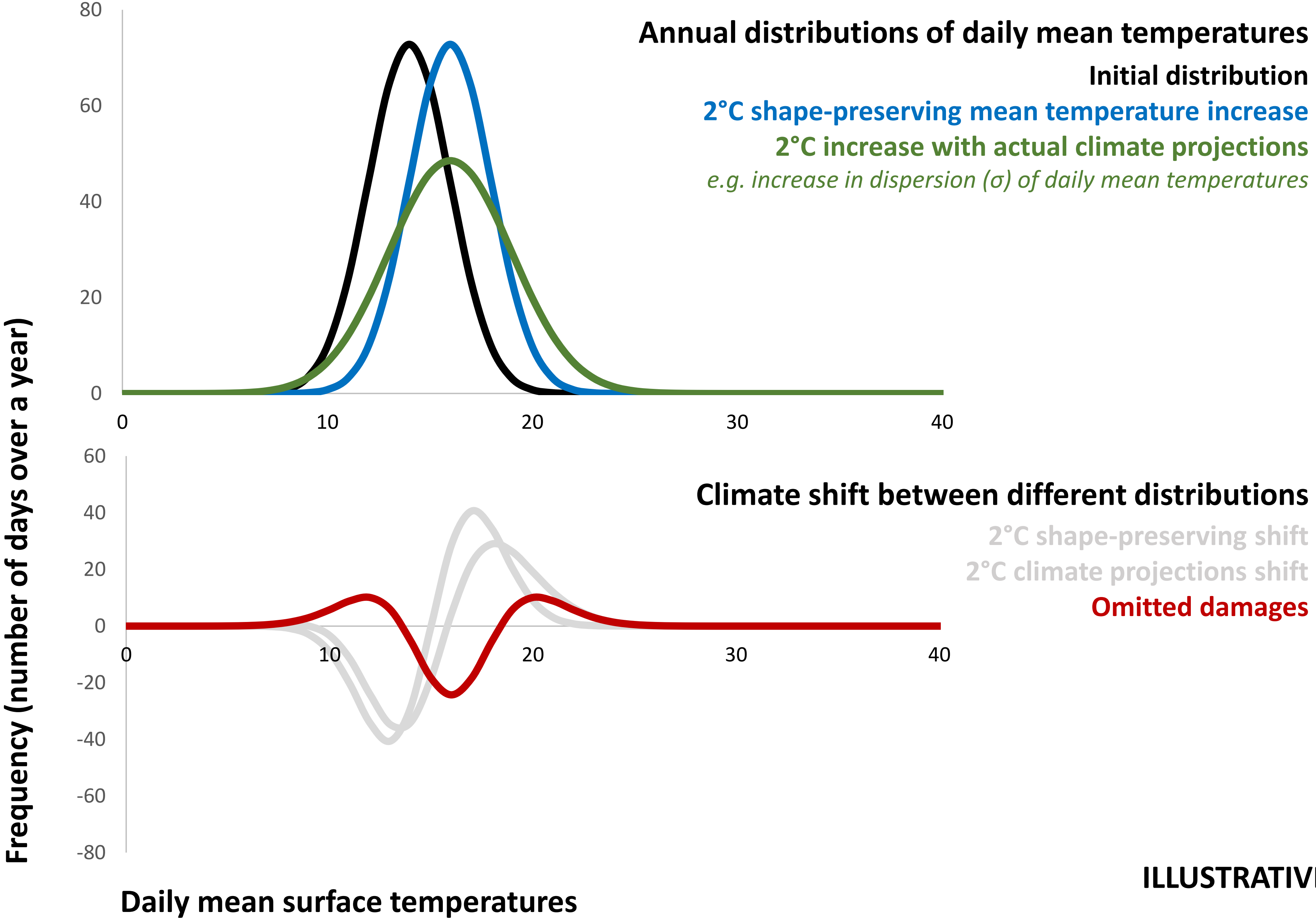

ILLUSTRATIVE

CHAPTER 3

MOTIVATION: understanding of how future climate damages may unfold across time and space.

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RESEARCH GAP: most climate-econ models evaluated at the same scale (global annual mean temperature)

METHOD: we combine at the **regional** scale
1. Warming patterns from climate projections of annual distribution of **daily mean temperatures**.
*2. **Damage patterns*** empirically estimated with non-linear dose-response functions.

RESULTS:
1. Across all scenarii, 2050 global damages are **around 25% higher** when accounting for the shift in the shape of the entire intra-annual distribution of daily mean temperatures at the regional scale.
2. Damage are **heterogeneously distributed** across the world, concentrated in **continental areas**.

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RESEARCH GAP: most climate-econ models evaluated at the same scale (global annual mean temperature)

METHOD: we combine at the regional scale (Köppen-Geiger climatic zones)
1. *Warming patterns* from climate projections of annual distribution of daily mean temperatures.
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IMPLICATIONS: navigate across temporal and spatial scales for robustness.

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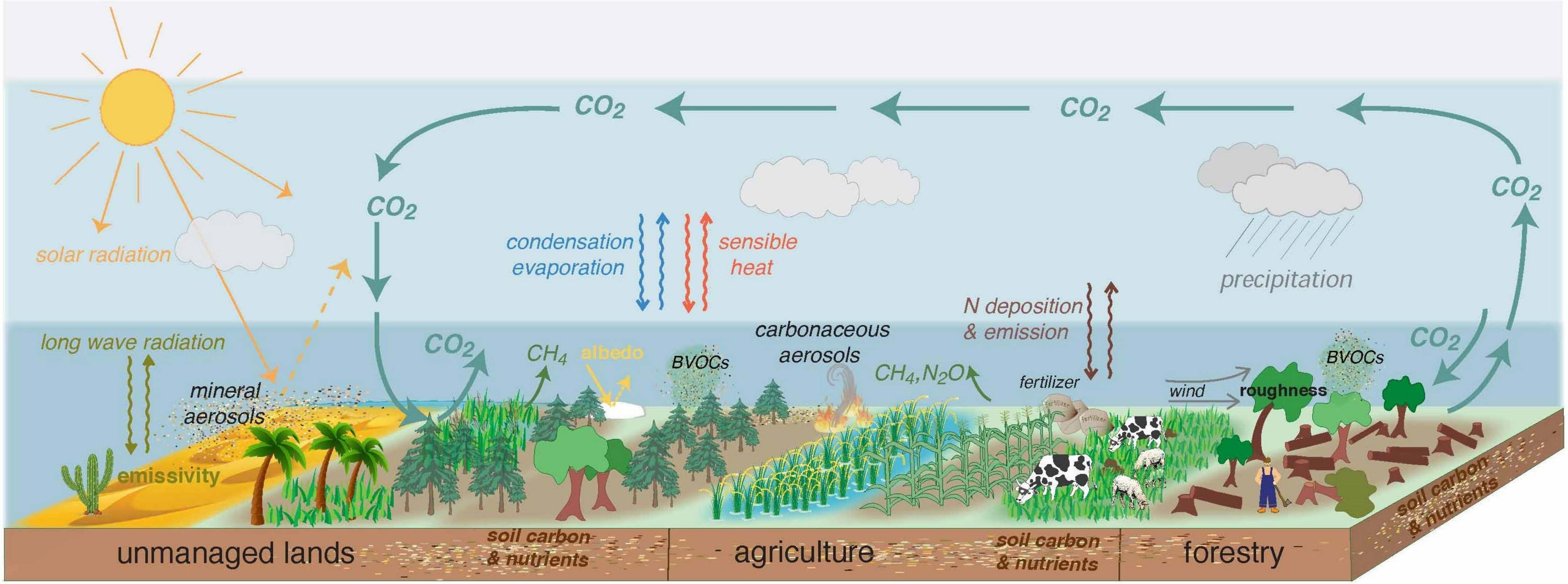
DIMENSION	Chapter 4
Time	■
Space	■
Risk	
Scientific Uncertainty	

APPROACH	Chapter 4
Normative	
Positive	■

CHAPTER 4

MOTIVATION: study interactions between economic activities and climate impacts**, beyond CO_2**

QUESTION: how does regional economic activity shape regional climate impacts?



Interactions between regional human activities and regional climate – IPCC illustration

CHAPTER 4

MOTIVATION: study interactions between economic activities and climate impacts**, beyond CO_2**

QUESTION: how does regional economic activity shape regional climate impacts?

RESEARCH GAP: quantitative spatial economic models assume **a time-invariant and exogenous temperature downscaling** from global climate change to local impacts.

Key references:
Cruz & Rossi-Hansberg, 2024, *Review of Economic Studies*
Rudik et al., 2024, working paper
Bilal & Rossi-Hansberg, 2024, working paper

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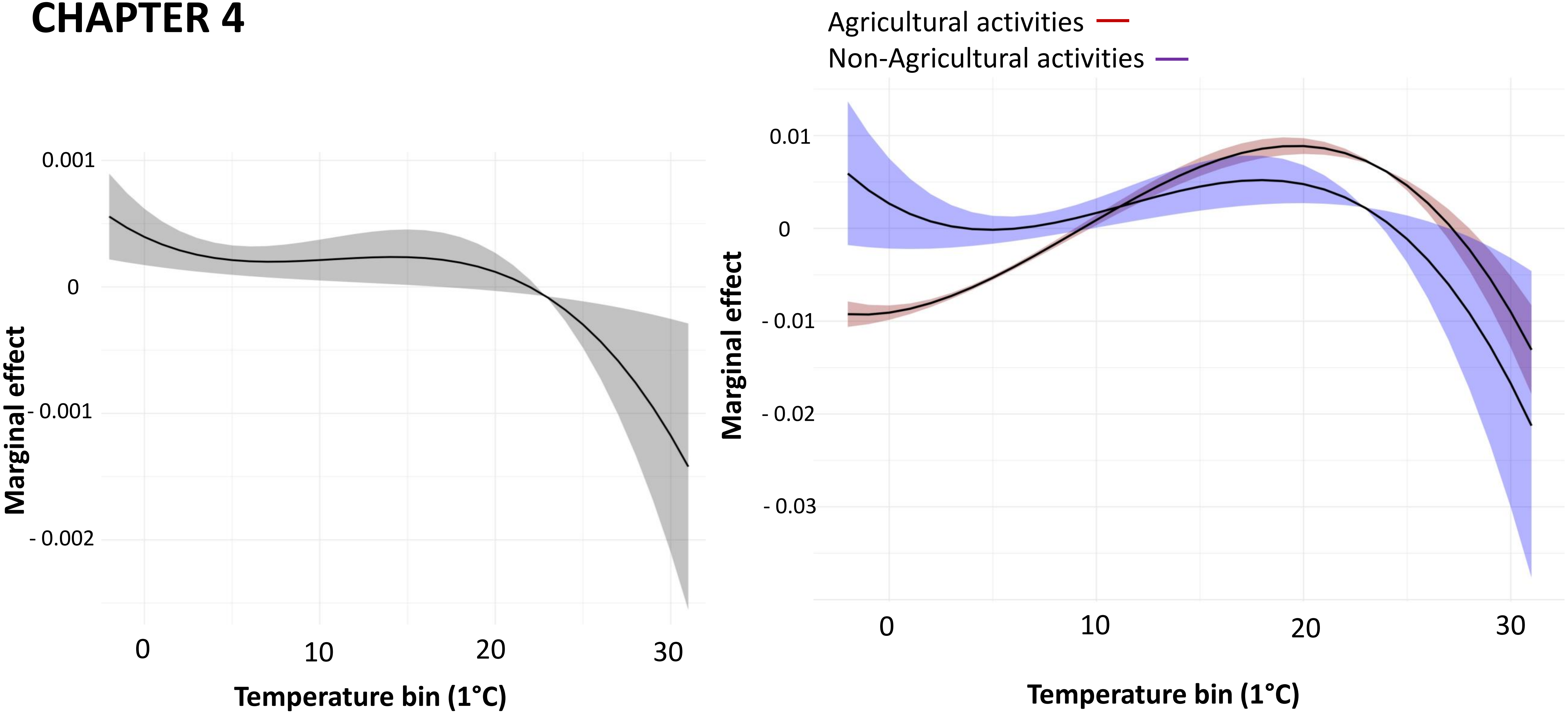
METHOD:

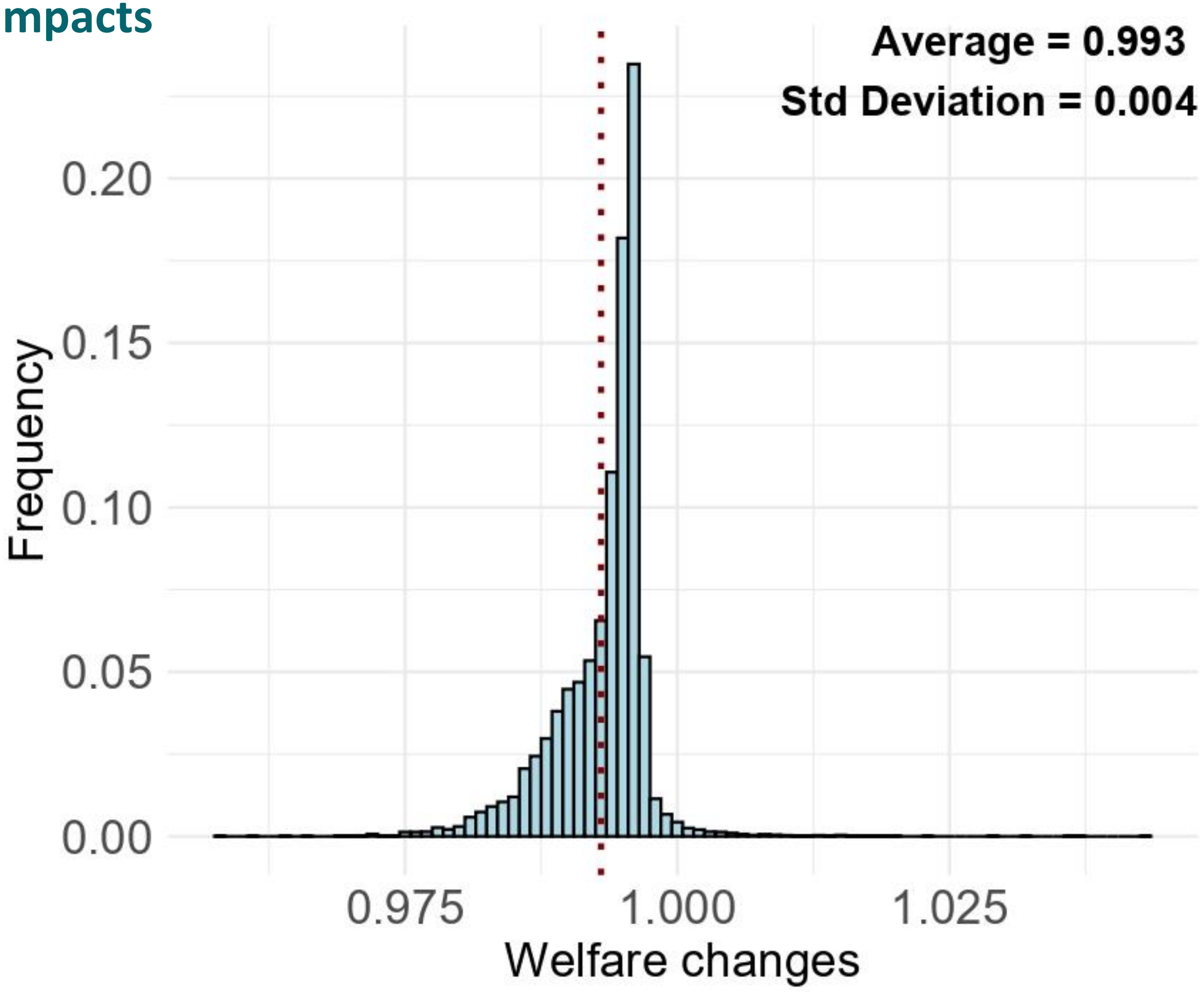
1. Biophysical climate impacts (**albedo, evapotranspiration, roughness**) from "middle-of-the-road" scenario of land use change **SSP2-4.5**.
2. A **dynamic spatial sectoral equilibrium model** at **1° resolution** (~110 km^2 at Equator) **global scale** (~13k locations) with agents that adapt to climate impacts through migration, structural change, trade.
3. **Model-consistent** climate impacts to regional **amenities** and sectoral **productivities**.



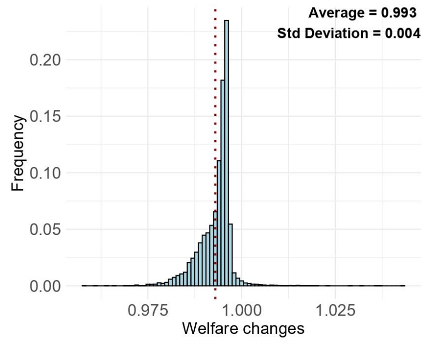
Non-linear dose-response functions of amenities (left) and sectoral productivities (right) to daily mean temperatures. Distributions are 95% winsorized.

Baseline: CO_2 impacts without biophysical impacts

1. Nearly all regions face welfare losses



CHAPTER 4

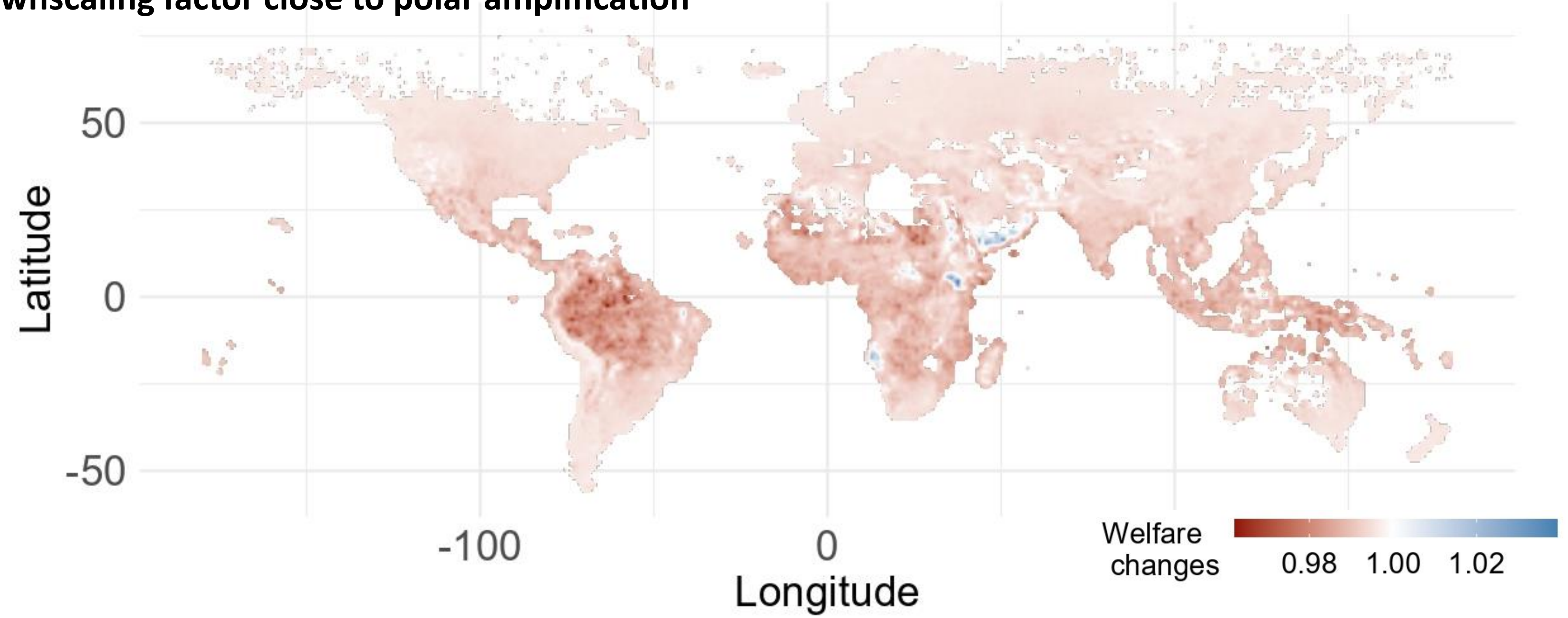


Baseline: CO_2 impacts without biophysical impacts

1. Nearly all regions face welfare losses

2. No benefits in the Northern Hemisphere

3. Damages not linear relative to a constant temperature downscaling factor close to polar amplification



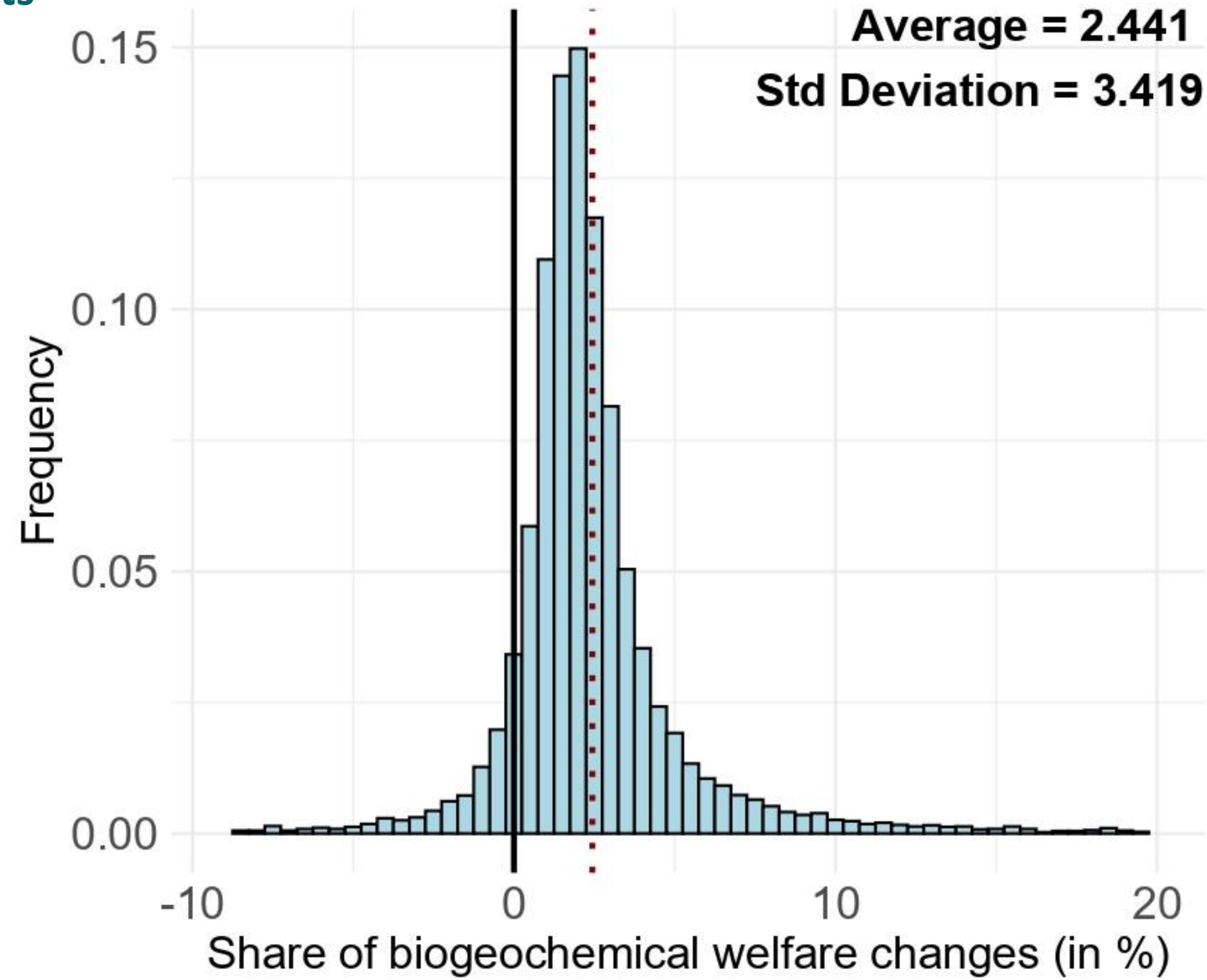
CHAPTER 4

Counterfactual: CO_2 and biophysical impacts

Biophysical impacts affect both **aggregate** & **distributional** outcomes.

Counterfactual: CO_2 and biophysical impacts

1. 2.4% of total impacts under SSP2-4.5.



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Counterfactual: CO_2 and biophysical impacts

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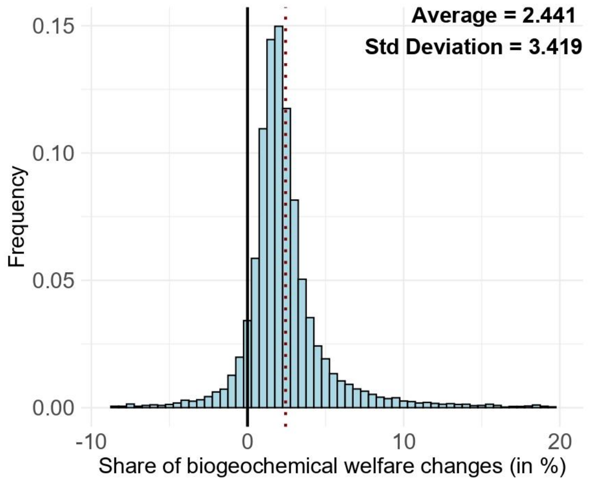
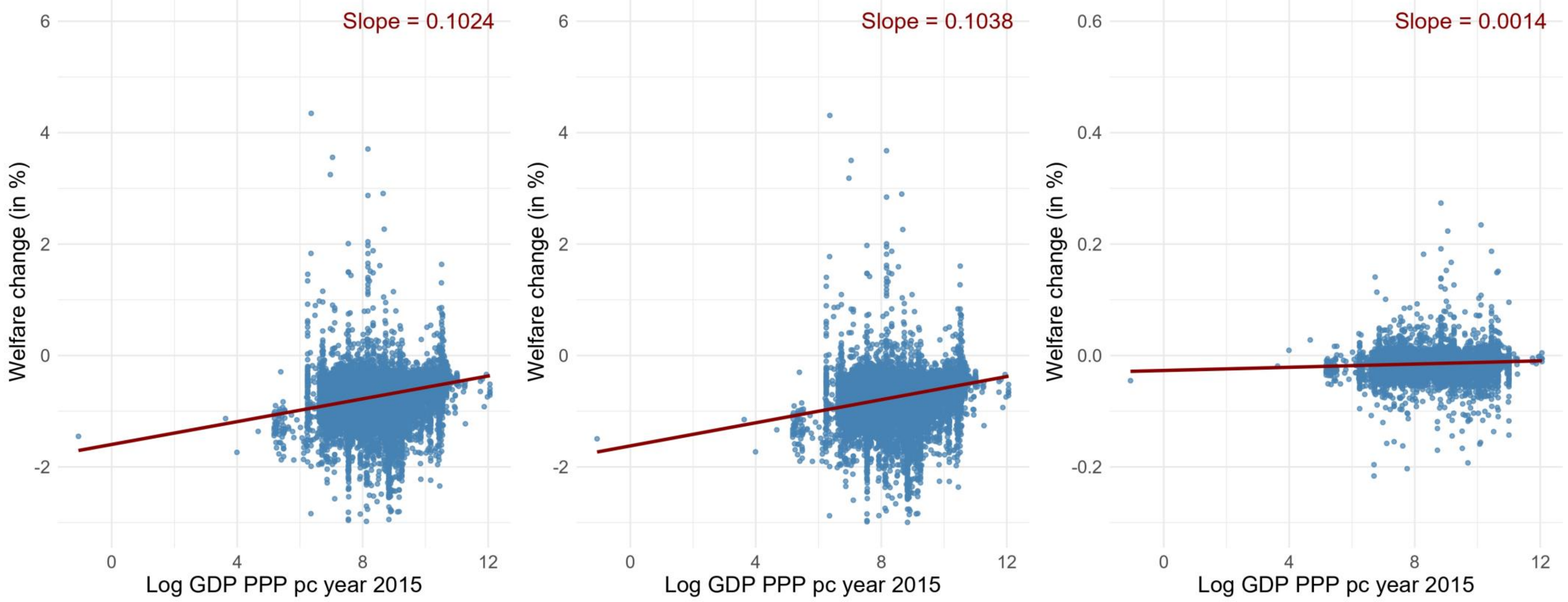
2. 1.4% increase in regressivity of CO_2 impacts.





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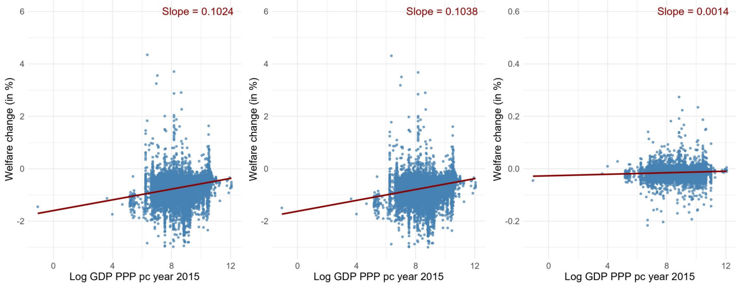
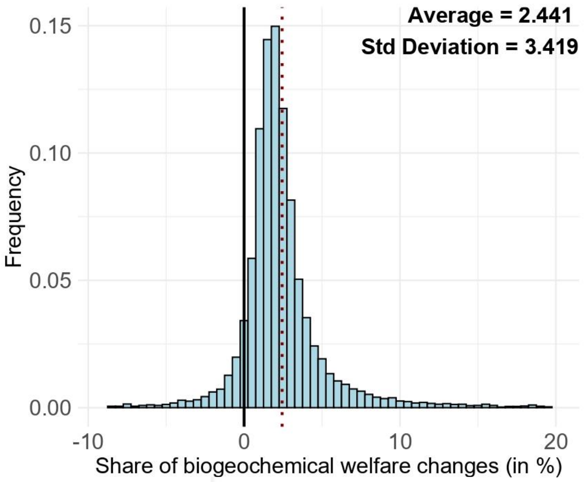
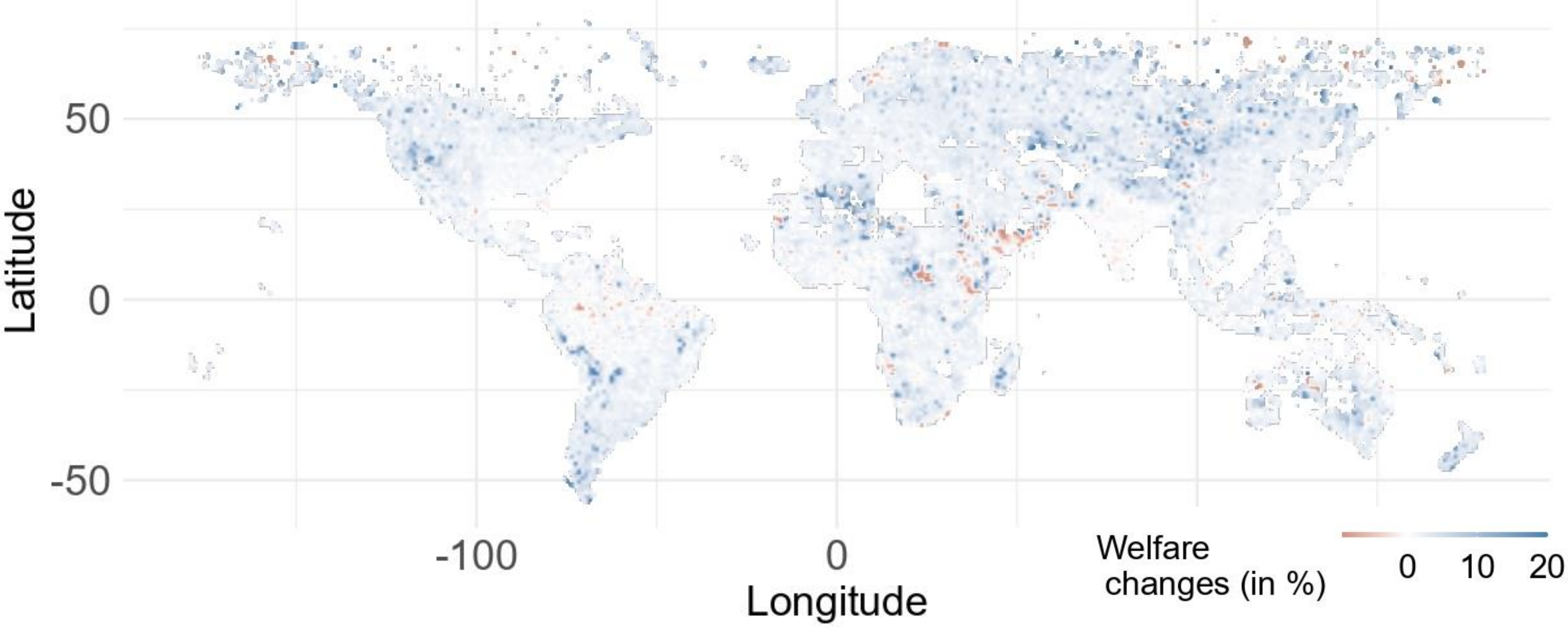
Counterfactual: CO_2 and biophysical impacts

1. 2.4% of total impacts under SSP2-4.5.
2. 1.4% increase in regressivity of CO_2 impacts.
3. **Heterogenous over the world.**







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MOTIVATION: study interactions between economic activities and climate impacts, beyond CO_2

QUESTION: how does regional economic activity shape regional climate impacts?

RESEARCH GAP: quantitative spatial economic models assume a time-invariant and exogenous temperature downscaling from global climate change to local impacts.

METHOD:

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3. **Model-consistent** climate impacts to regional **amenities** and sectoral **productivities**.

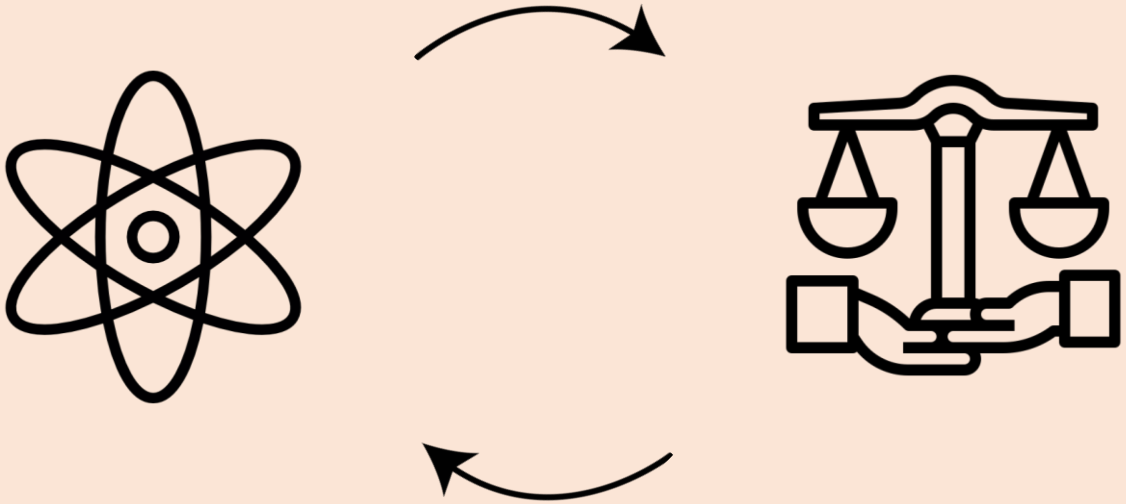
IMPLICATIONS: regional economic activity shape regional climate impacts via land use changes, increasing the aggregate climate damage and the inequality in climate damages.

CONCLUSION

Two connected but distinct agendas on climate uncertainties.

Positive Inform decisions on climate uncertainties with the best information available.

Normative Provide flexible decision frameworks for public decisions under uncertainties.



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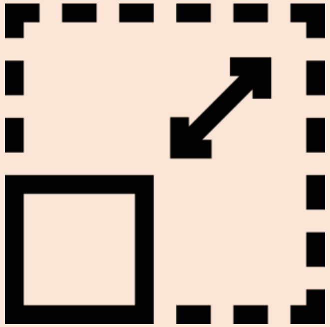
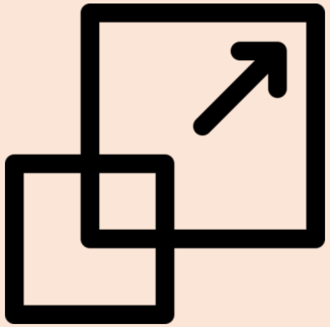
At the intersection of four dimensions: time, space, stochastic risk, scientific uncertainty.

Within dimensions What holds true at a given scale, model, state of the world, might not always apply.

Across dimensions Advancements in one dimension impact our understanding of other dimensions.





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Across dimensions Advancements in one dimension impact our understanding of other dimensions.

Beyond this thesis. I have studied **stochastic** (chap. 1, 2) & **spatial** (chap. 3, 4) dimensions in silo.

At the intersection of space and stochastic risk, I might find:

New understanding of climate impacts, e.g. adaptation decisions under risk aversion.

New policy proposals, e.g. *ex ante* place-based policies against environmental risk.

Thank you!

(I am on the economics job market!)