# Tropical Cyclones, Displacement, and Policy:

## Advancing Climate Risk Assessments

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Webinar Institut des Actuaries, 2 April 2025

Stanford University

Introduction

# *Climate Risk Science*

Rodrigo Oropeza / AFP / Getty

Introduction

# *Climate risk modelling*

CLIMADA
Economics of Climate Adaptation

https://github.com/CLIMADA-project/climada_python

Agenda

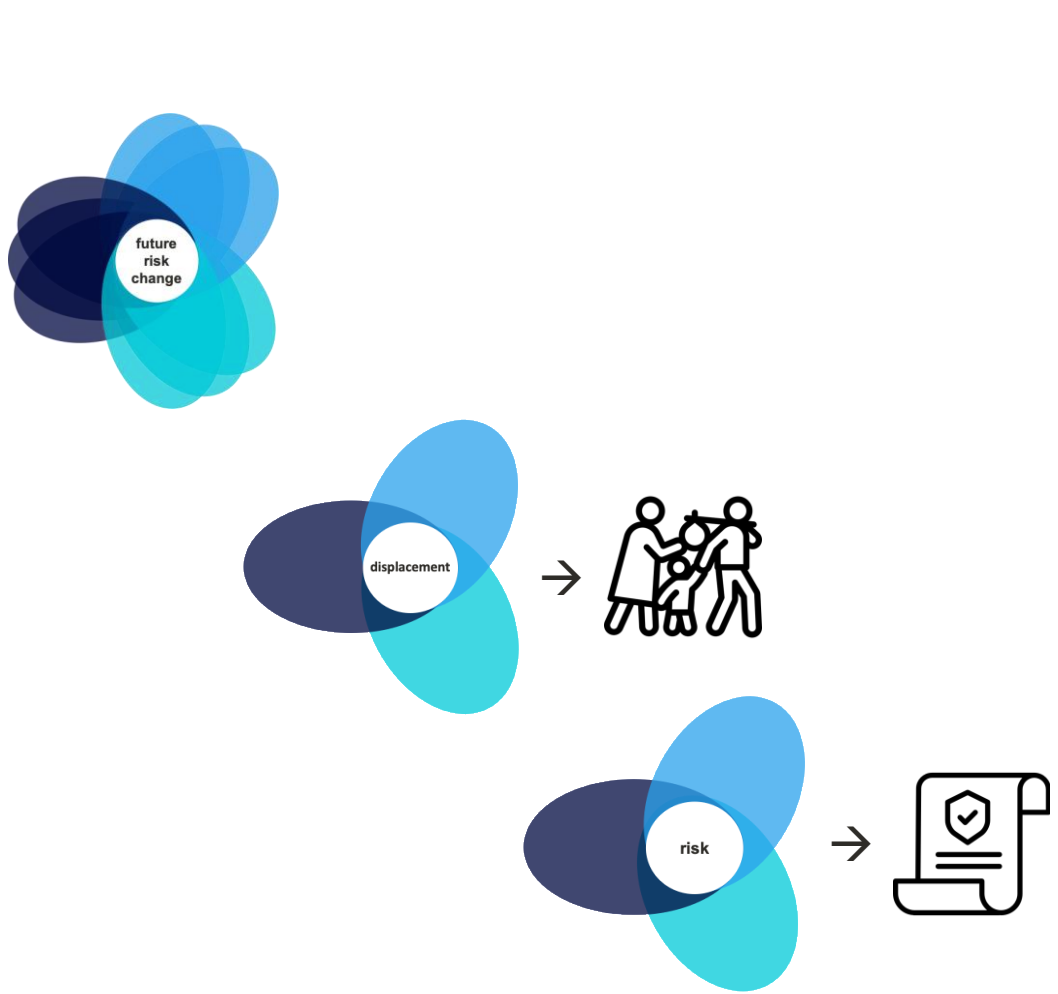
# *Tropical Cyclones, Displacement, and Policy*

**Tropical cyclone** model intercomparison

**Uncertainties & sensitivities** in future tropical cyclone risk

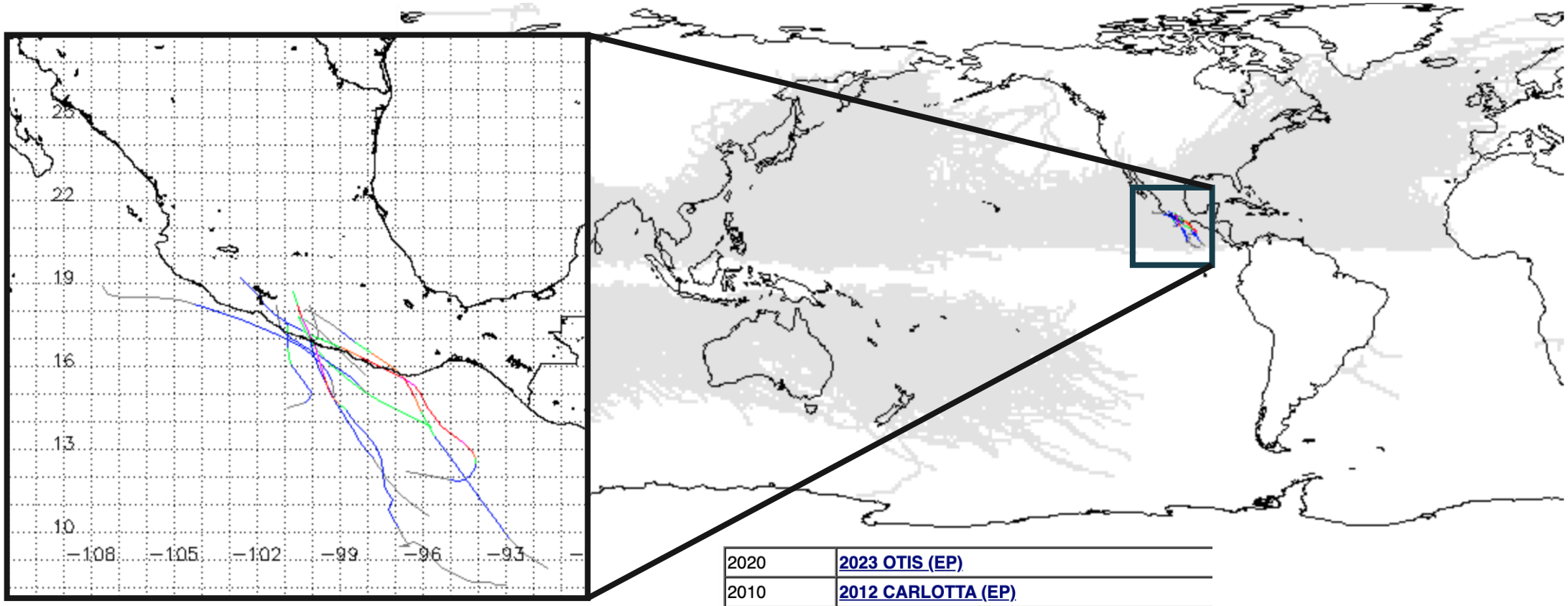
Global **displacement risk** modeling

Extreme weather events and **climate policy support**



Introduction

# *Historical tropical cyclone records are sparse*

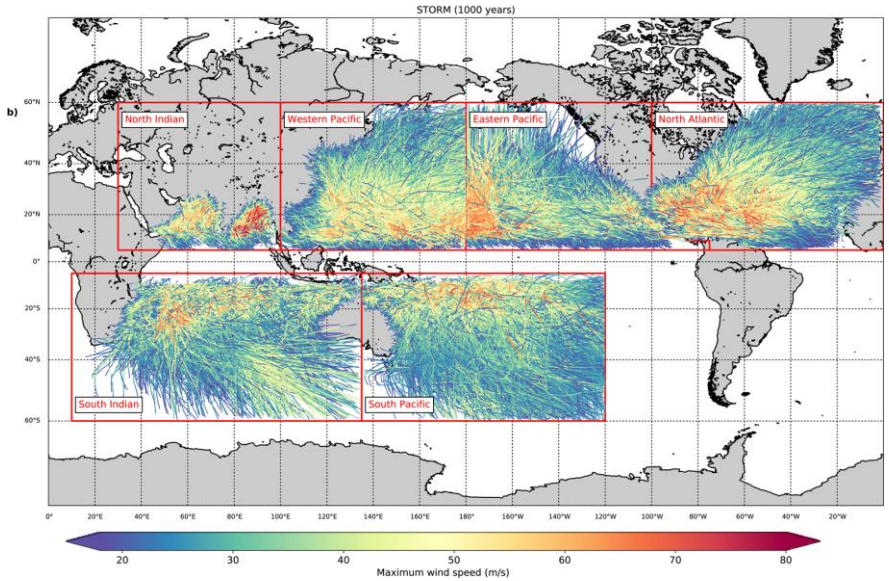


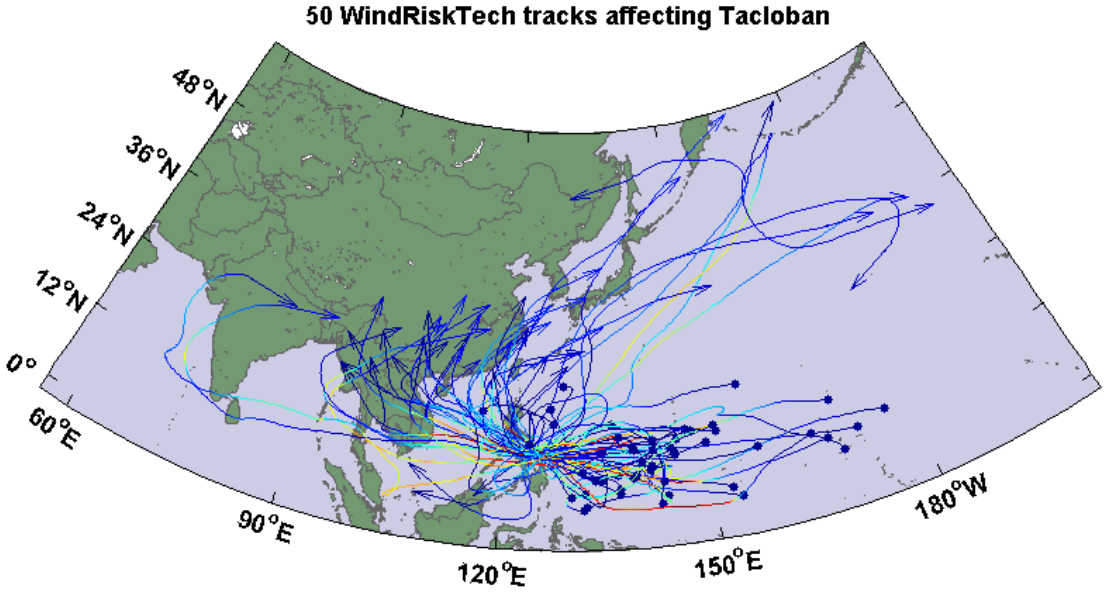

| | |
|---|---|
| 2020 | 2023 OTIS (EP) |
| 2010 | 2012 CARLOTTA (EP) |
| 2000 | 2005 DORA (EP) |
| 1990 | 1997 PAULINE (EP) |
| 1970 | 1973 CLAUDIA (EP), 1974 NORMA (EP) |
| 1960 | 1965 WALLIE (EP) |
| 1950 | 1951 EP02 (EP) |

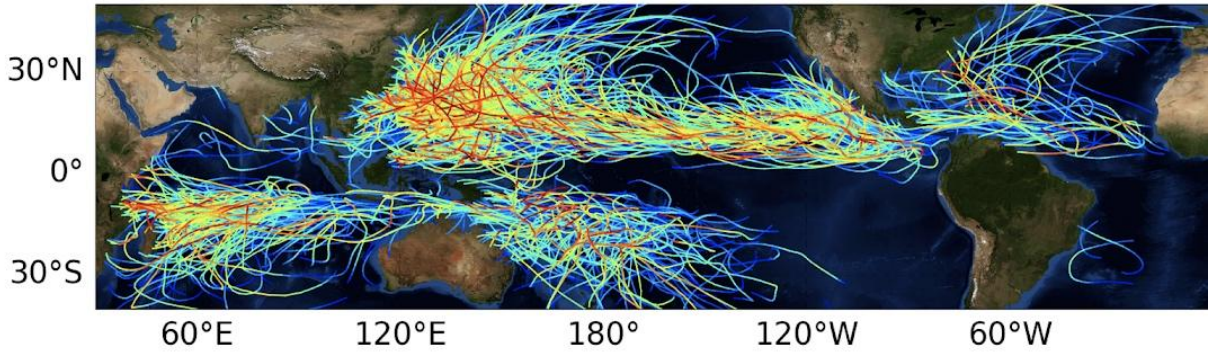
https://ncics.org/ibtracs/index.php?name=Grid-38779

Introduction

# *Synthetic tropical cyclone models*



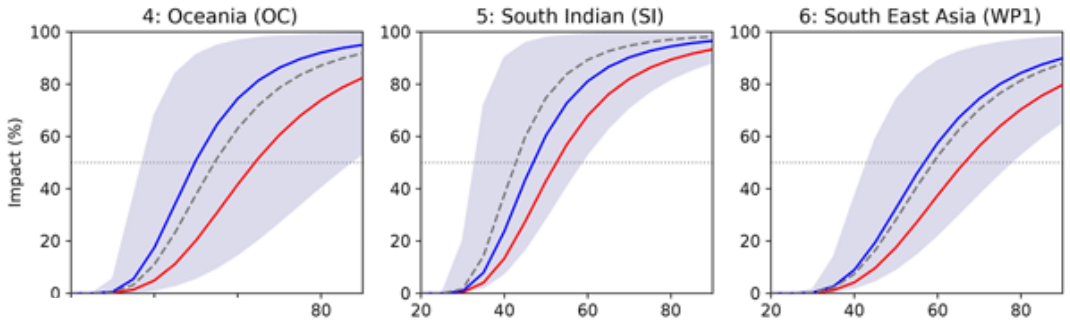




Bloemendaal et al. (2020), *Sci Rep*
Emanuel et al. (2006, 2008), *BAMS*
Lee et al. (2018), *JAMES*

Introduction

# *TC model intercomparison*



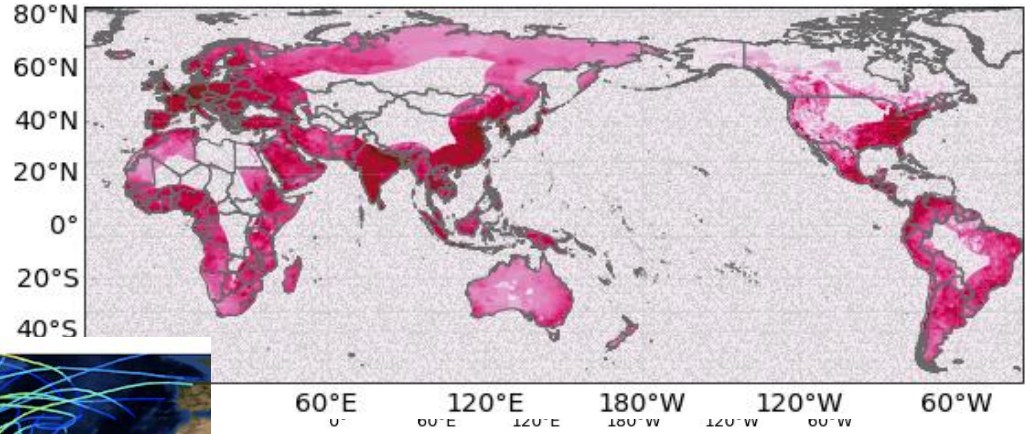

**Regionally calibrated impact functions**

**TC hazard sets:**

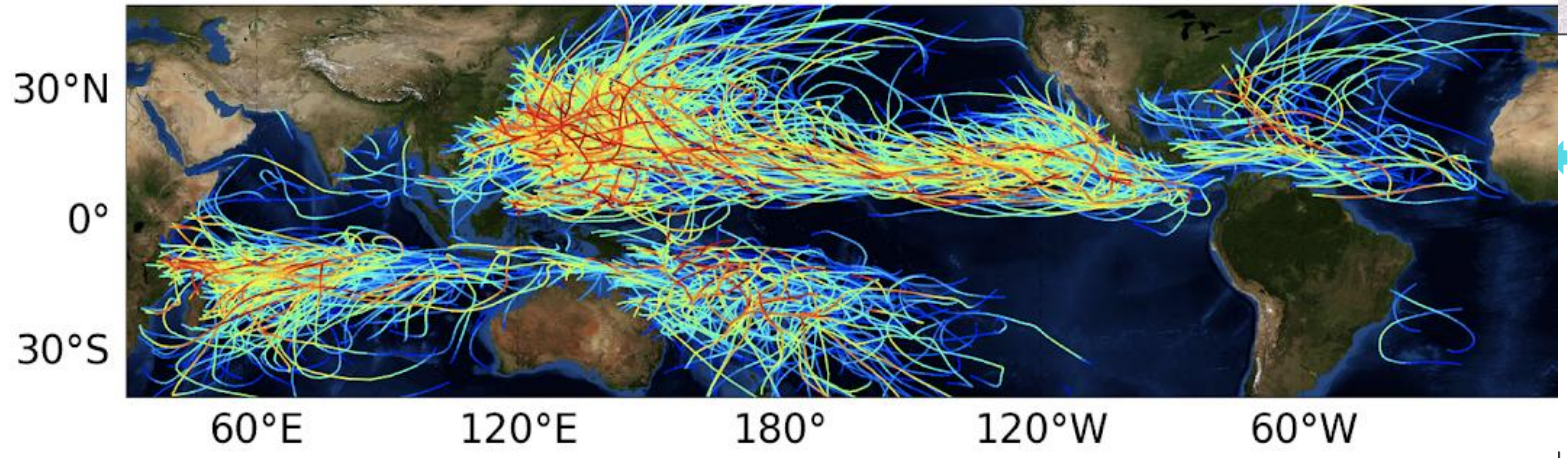
- IBTrACS[1]
- Probabilistic IBTrACS[2]
- STORM[3]
- MIT[4]

**TC hazard sets**

**direct economic damage**



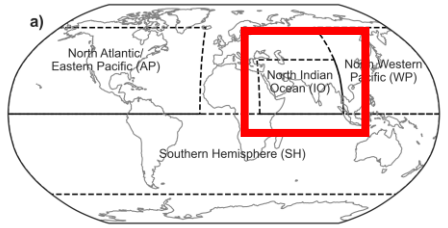

**Spatially explicit asset value**

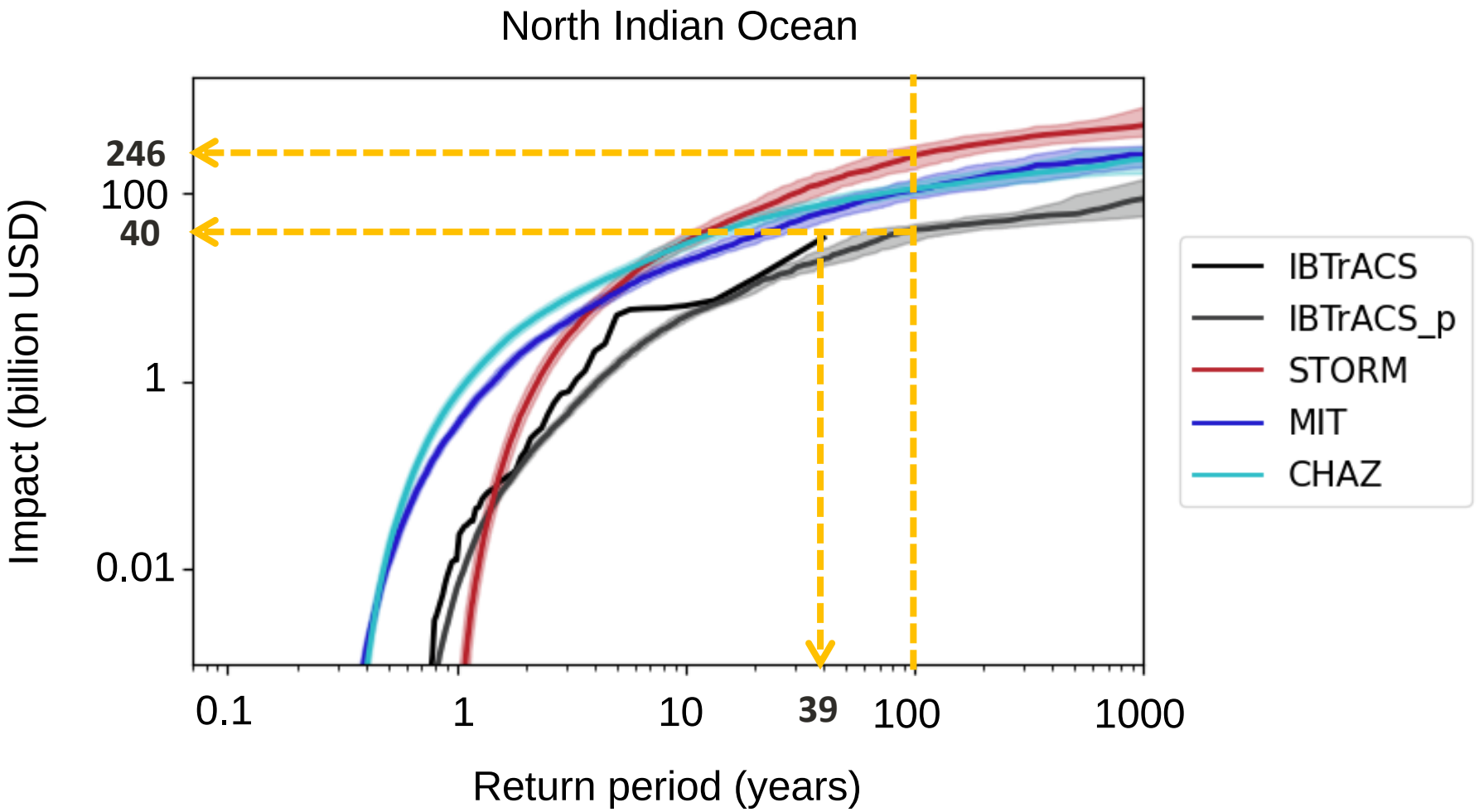



Meiler et al. (2022), *Nature Communications*

TC model intercomparison

# *Results: Impact return period curves*




Meiler et al. (2022), *Nature Communications*

TC model intercomparison

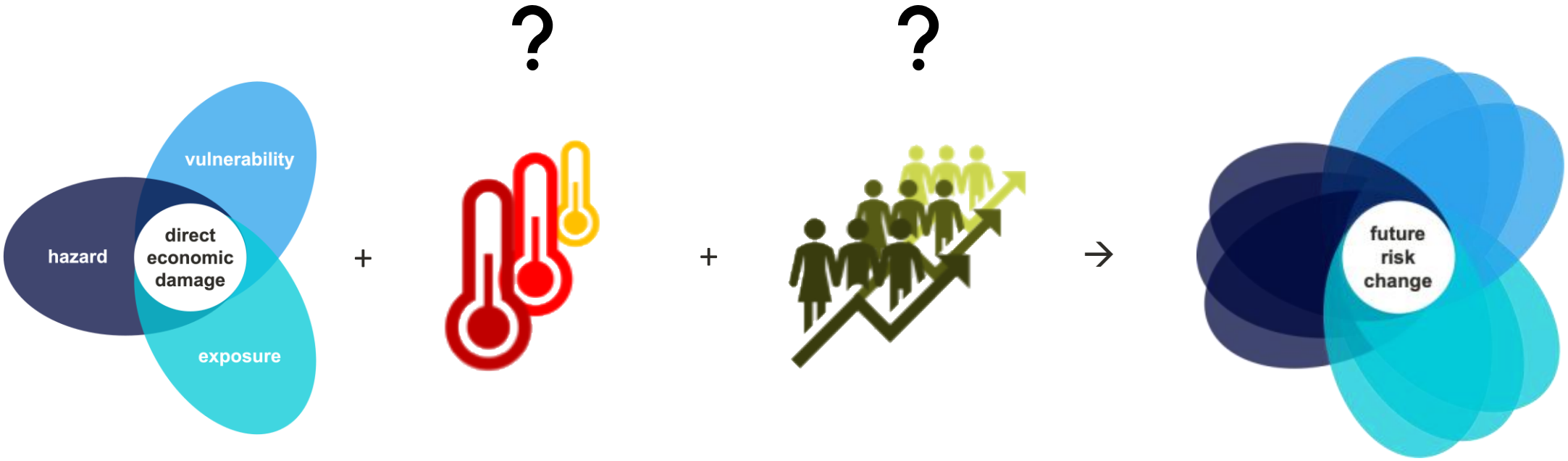
# *Guidance on TC track set choice*

quantitative analysis × TC model qualities × application → guidance




Meiler et al. (2022), *Nature Communications*

# *Uncertainties and sensitivities in future TC risk assessment*

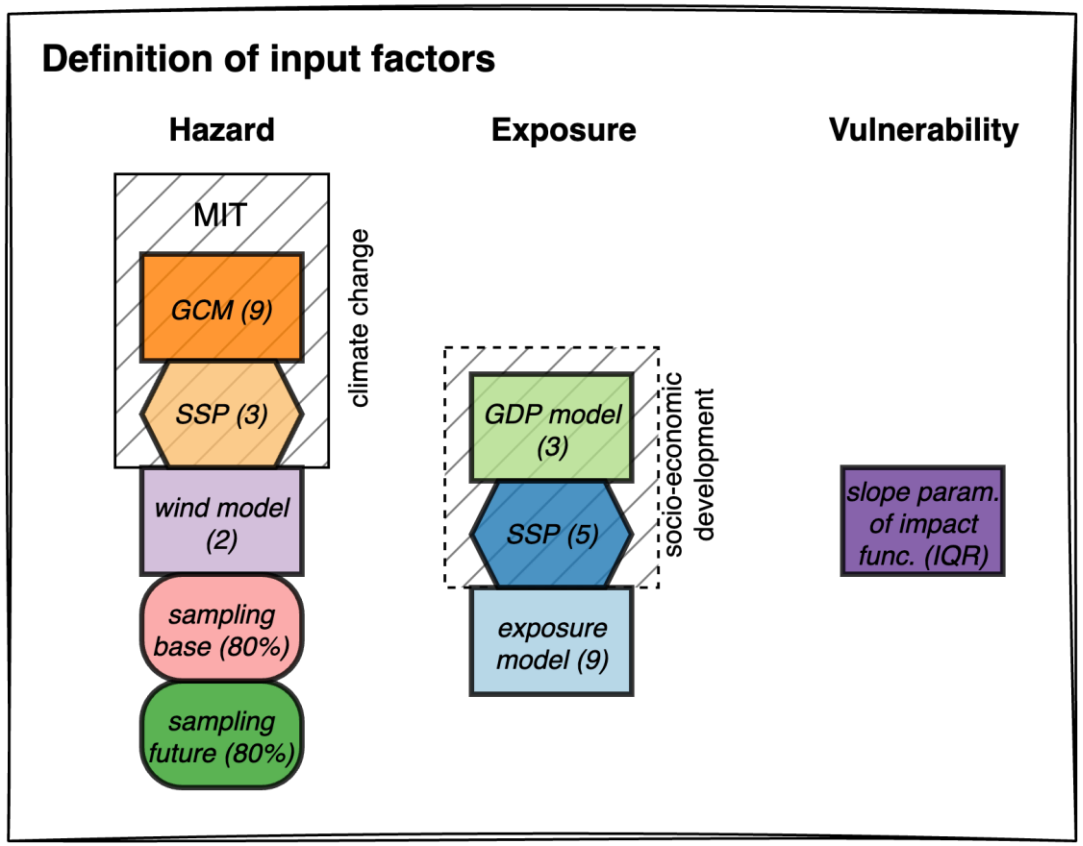



Meiler et al. (2022), *Nature Communications*

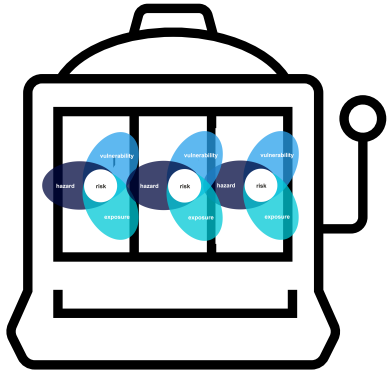
Meiler et al. (2023a), *Comms Earth & Env*
Meiler et al. (2023b), *ICASP14*
Meiler et al. (2025), *in press*

Uncertainties and sensitivities in future TC risk assessment

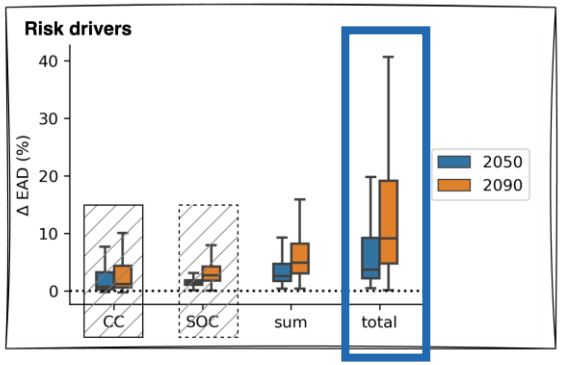
# *Study setup I*

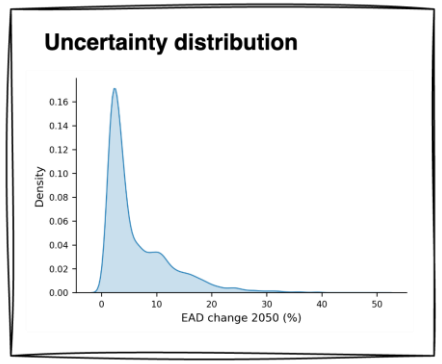


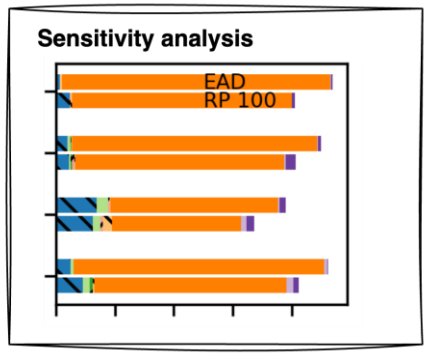

Risk modeler choices



Uncertainty and sensitivity analysis

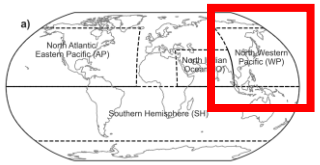


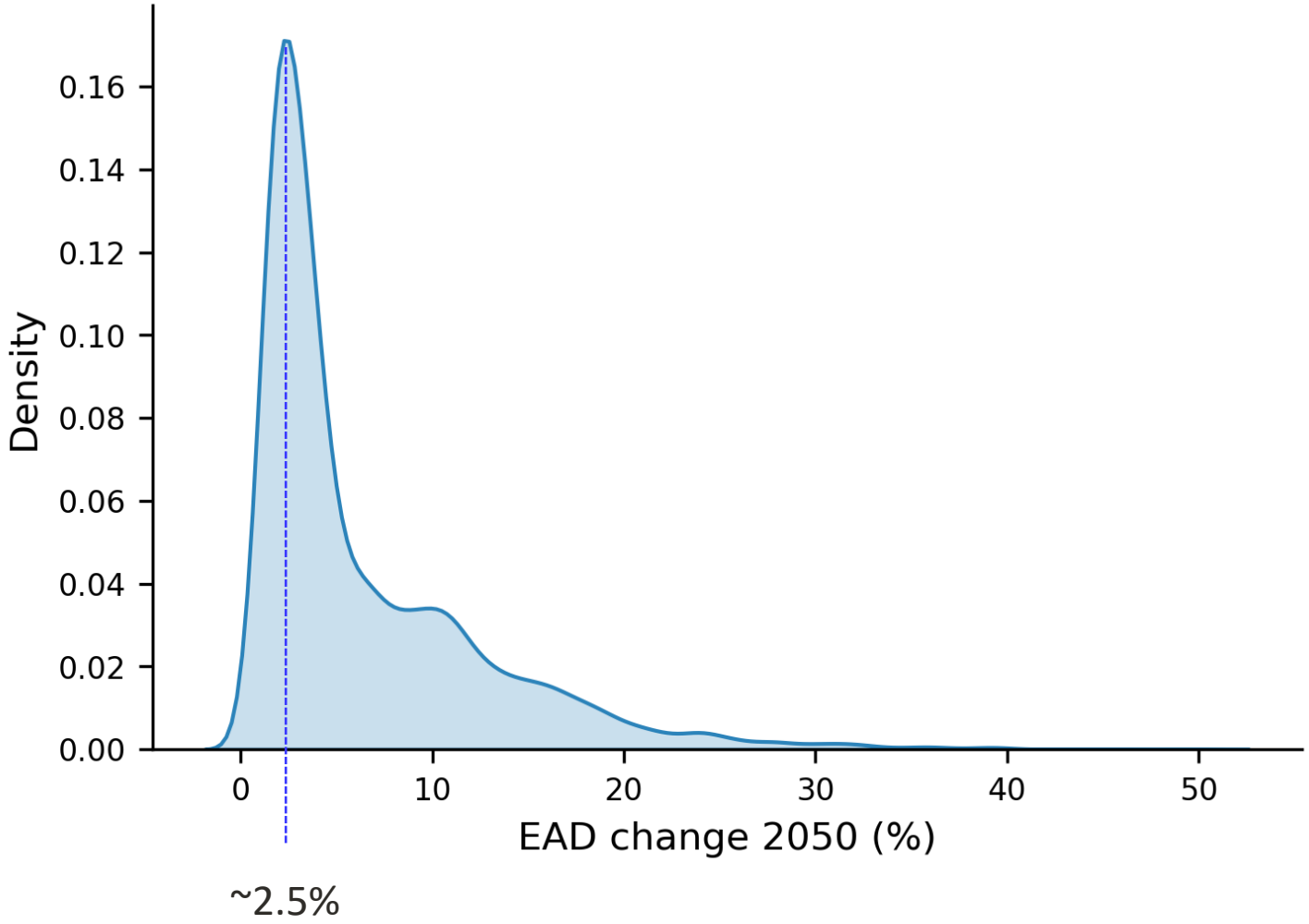




Meiler et al. (2023a), *Comms Earth & Env*

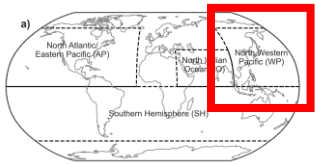
# *Results: Uncertainty quantification*

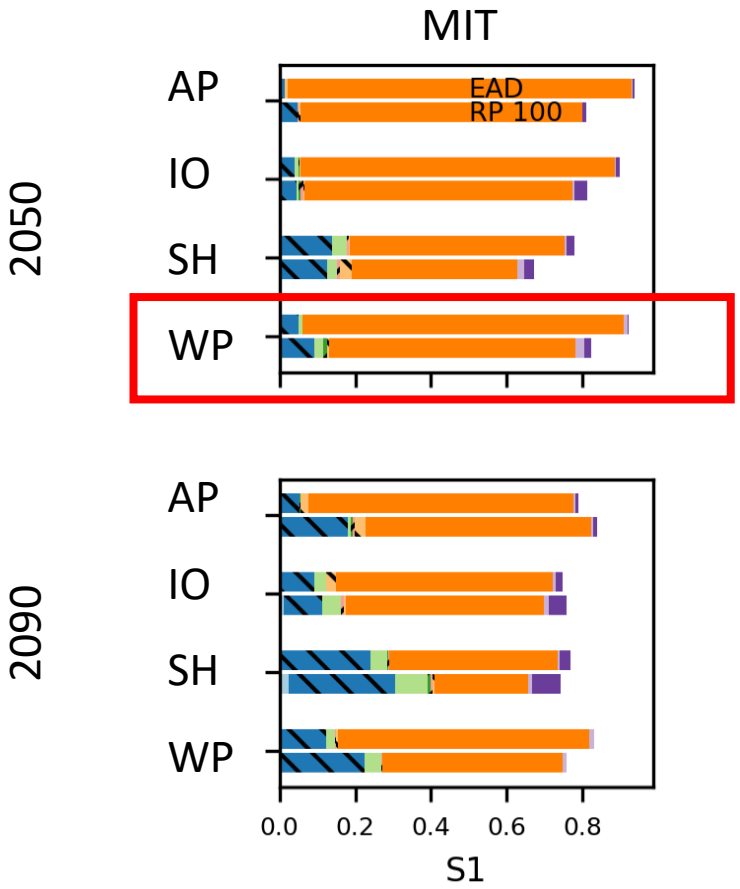


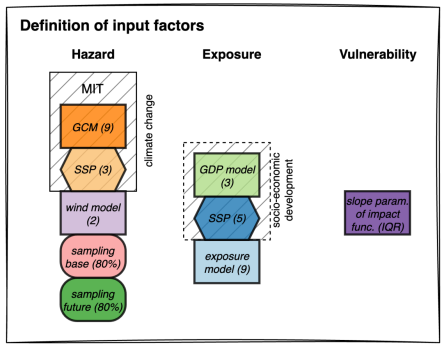

Meiler et al. (2023a), *Comms Earth & Env*

# *Results: Sensitivity indices*




GCM

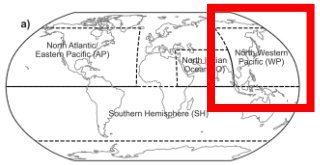


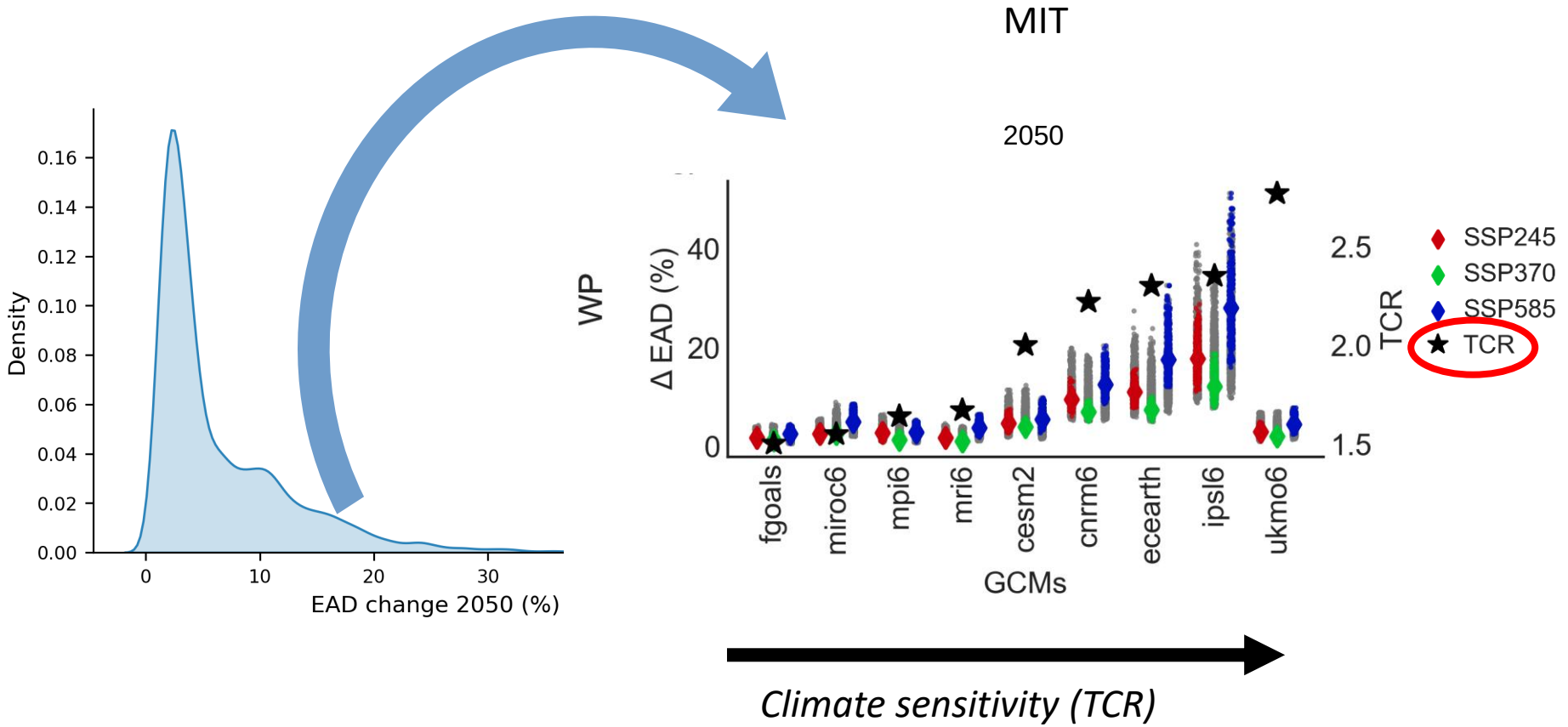

Exposure urban/rural weighting
SSP exposures
GDP model
Event subsampling future
Event subsampling base
TCGI moisture variable
SSP hazard
GCM
Wind model
Vulnerability function midpoint

Meiler et al. (2025), *in press*

Uncertainties and sensitivities in future TC risk assessment

# *Relationship to climate sensitivity in GCMs*

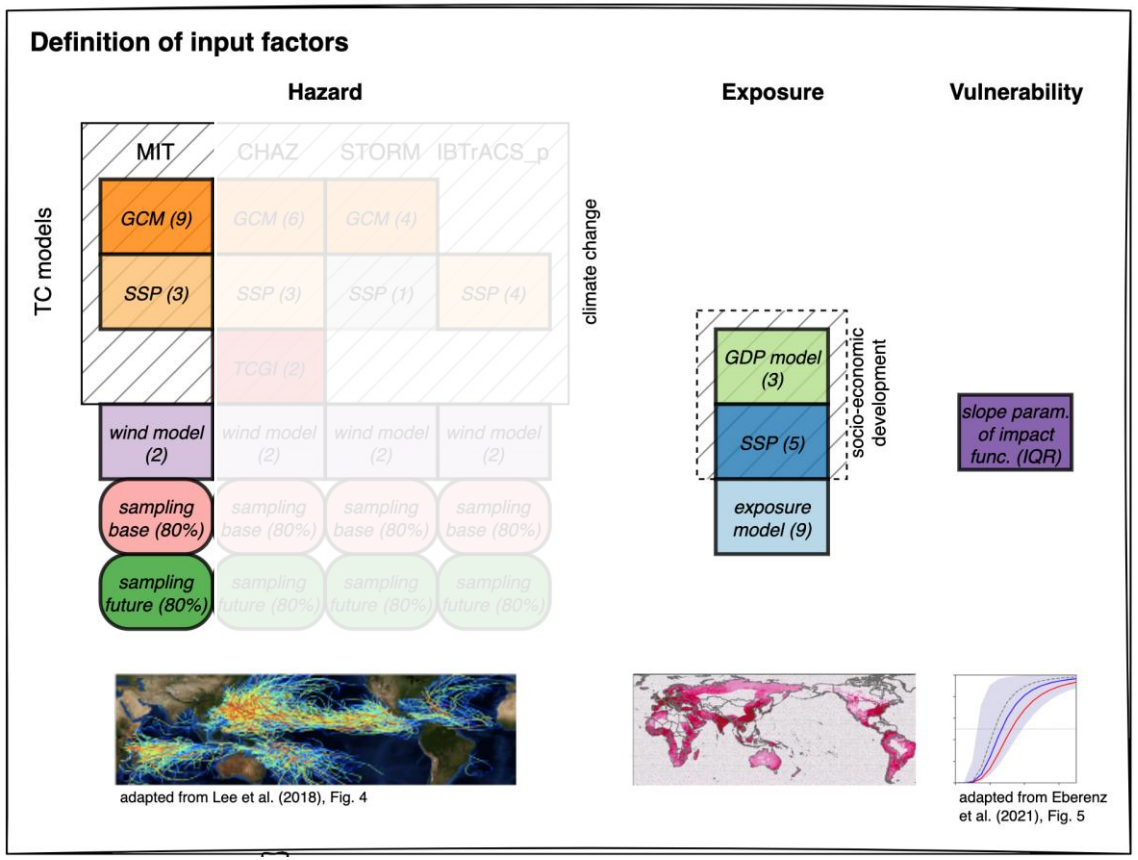


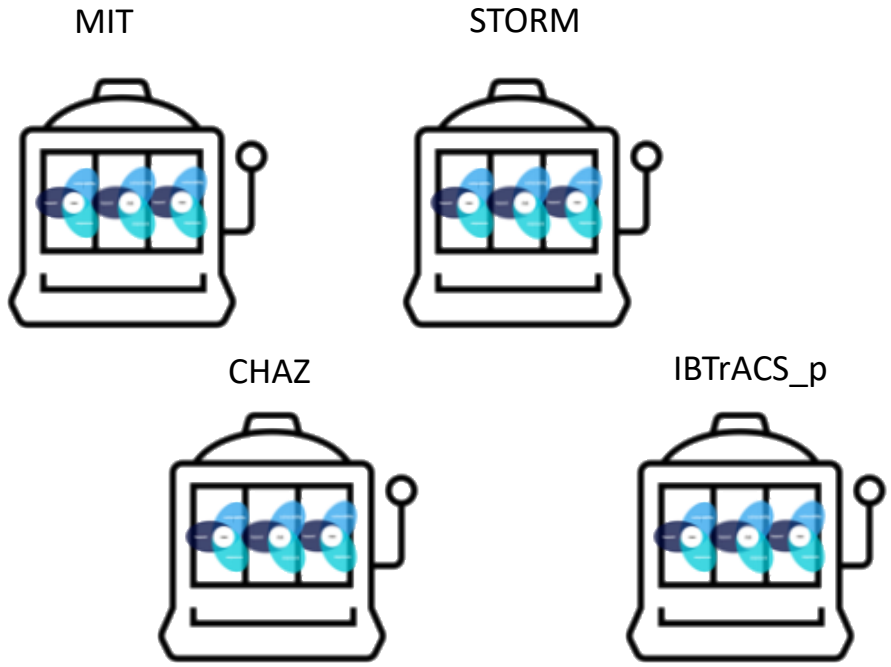




Meiler et al. (2023a), *Comms Earth & Env*

# Uncertainties and sensitivities in future TC risk assessment

## *Study setup II*

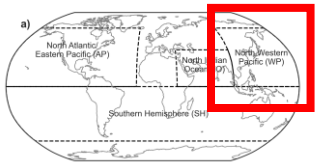


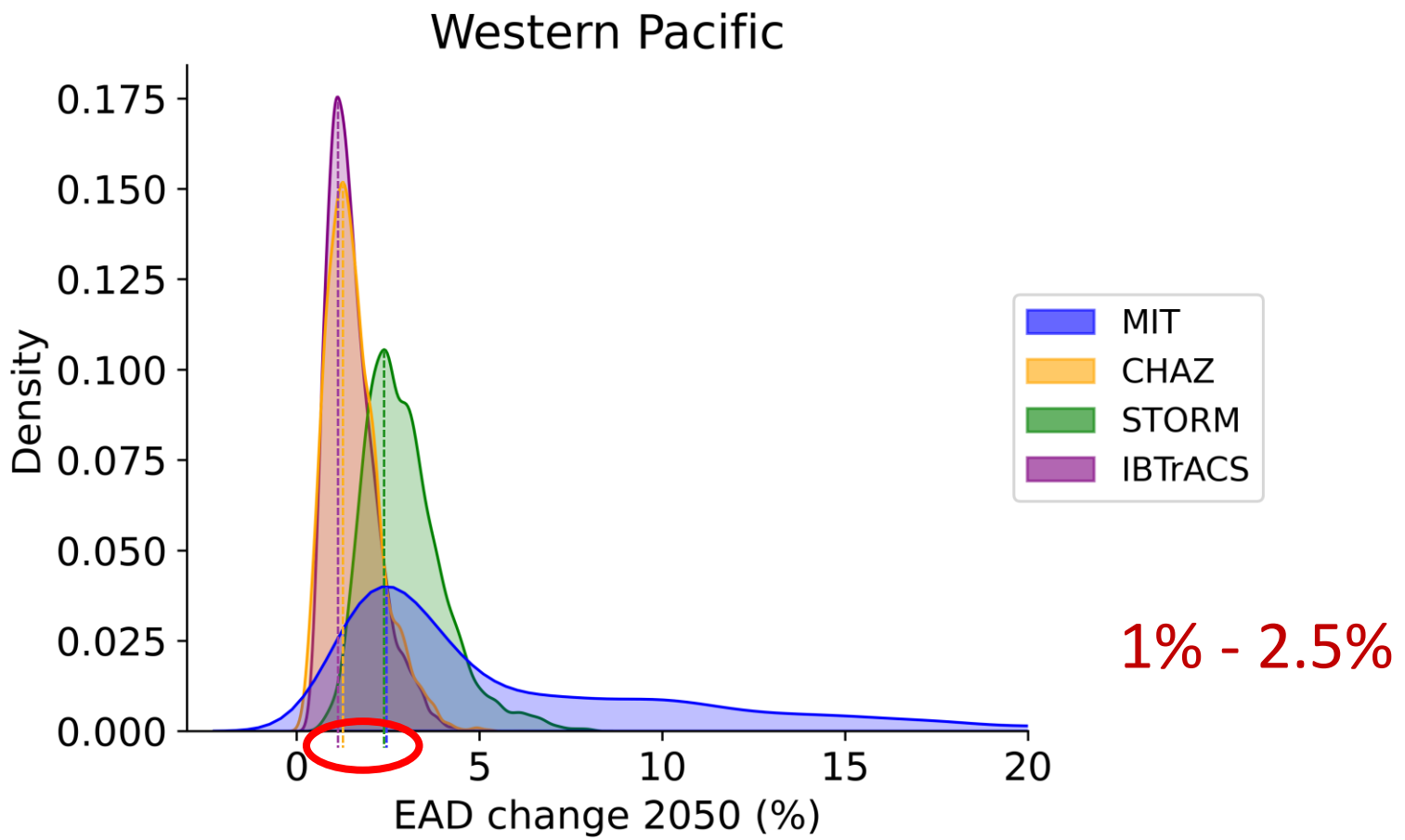





Gettelman et al. (2018), *Clim. Chang.*
Bloemendaal et al. (2020), *Sci Rep*
Emanuel et al. (2006, 2008), *BAMS*
Lee et al. (2018, 2020), *JAMES*

# *Results: Uncertainty of future TC risk change*



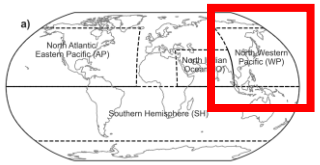



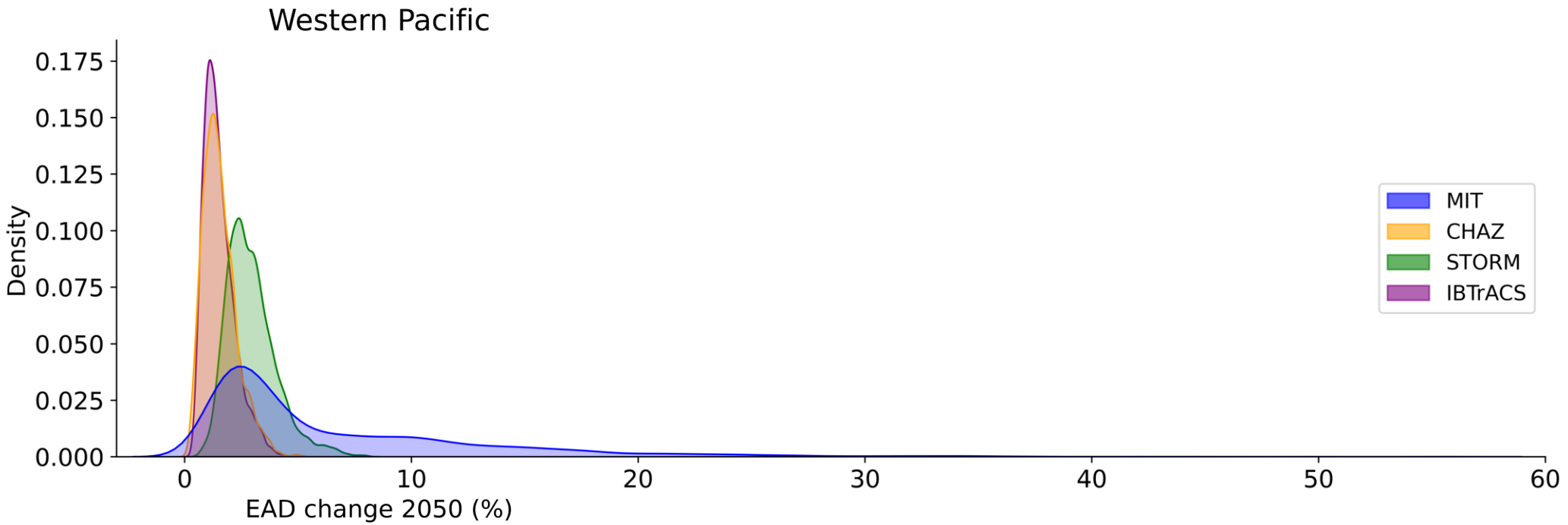

1% - 2.5%

EAD = Expected Annual Damage

Meiler et al. (2025), *in press*

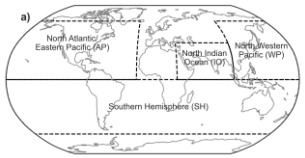
# *Results: Uncertainty of future TC risk change*

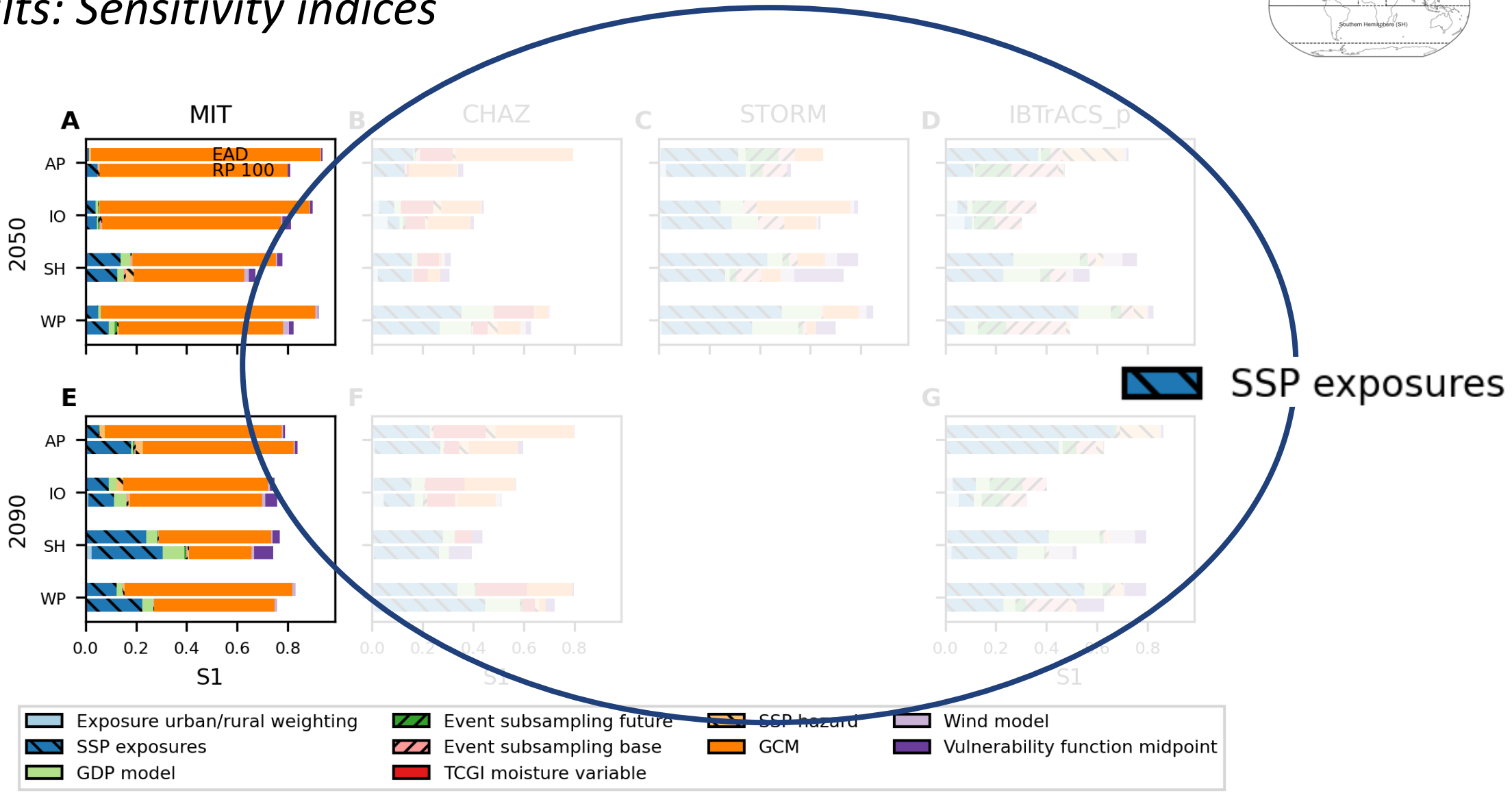



Meiler et al. (2025), *in press*

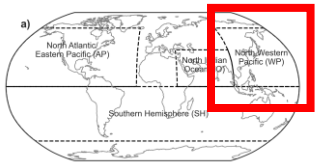
# *Results: Sensitivity indices*



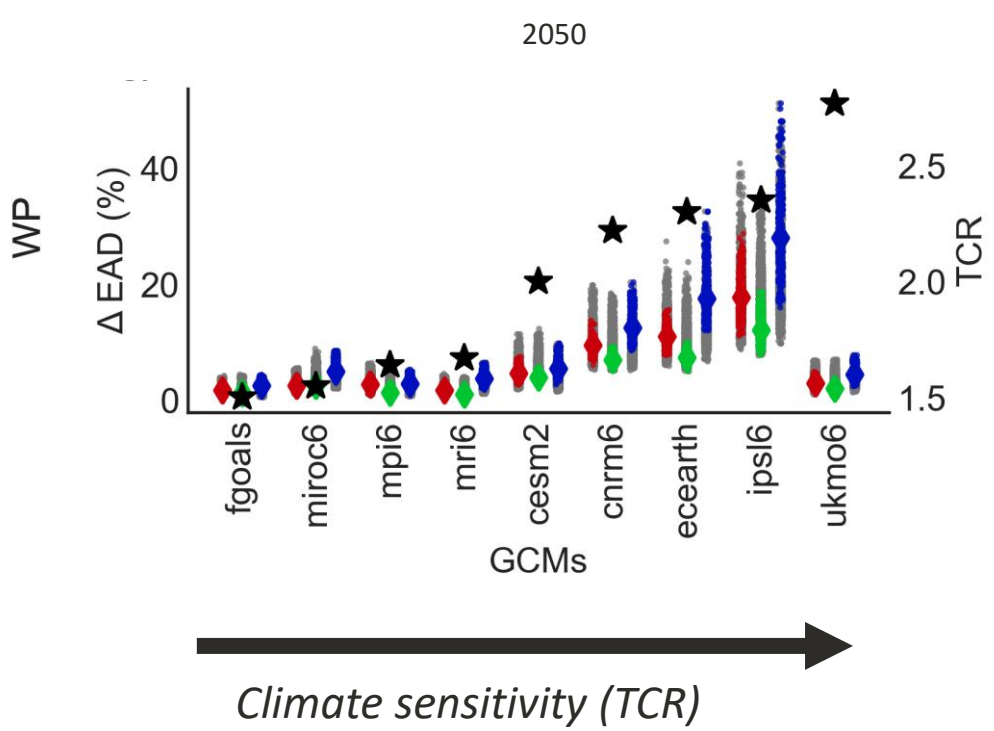




Meiler et al. (2025), *in press*

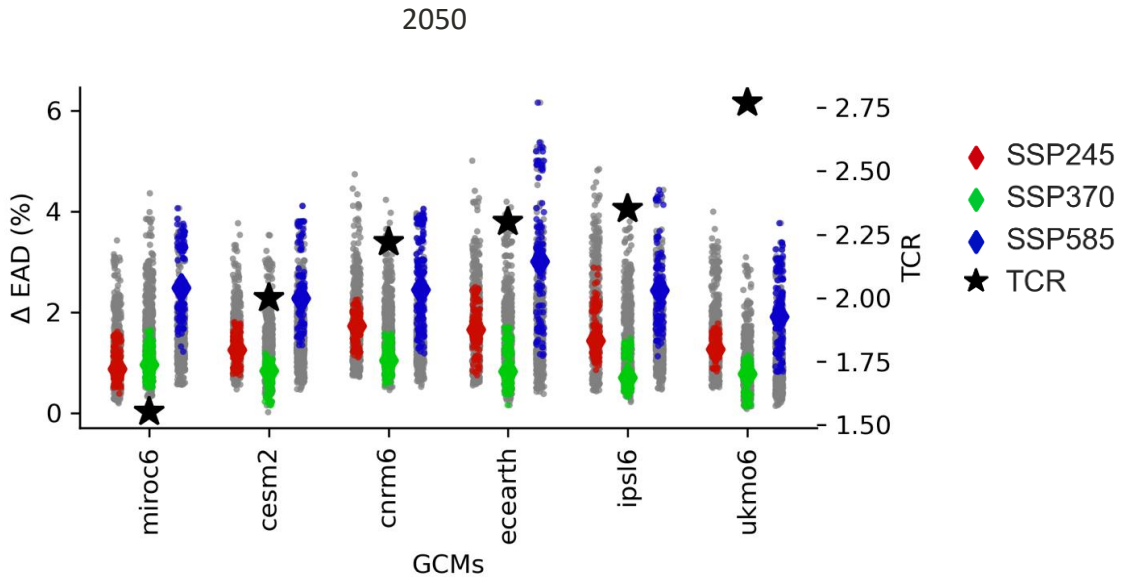
# *Relationship to climate sensitivity in GCMs*




MIT




CHAZ



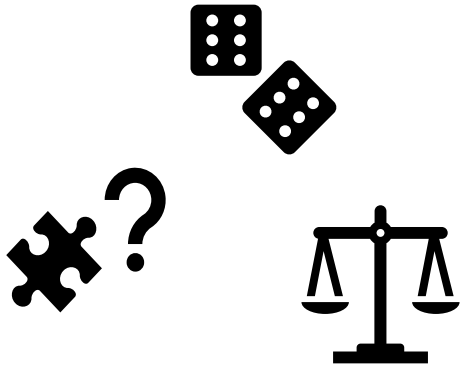

Meiler et al. (2023a), *Comms Earth & Env*

Meiler et al. (2025), *in press*

Discussion

# *Back to reality – types of uncertainty*

quantitative analysis × classes of uncertainty → implications



- Aleatory (randomness)
- Epistemic (knowledge gaps)
  - Model uncertainty
  - Scenario uncertainty
- Normative (value-based decisions)

Meiler et al. (2025), *in press*

Conclusion

# *Turning Uncertainty into Insights*

- **Variable uncertainty sources** depending on hazard model choice and risk model setup
- **Transparency**
- Wide **range** of plausible future outcomes
- Risk management strategies according to levels of **cautiousness / risk aversion**
- **Types of Uncertainty:**
  - Aleatory (randomness)
  - Epistemic (knowledge gaps)
  - Normative (value-based decisions)

# A natural hazard risk modelling approach to human displacement

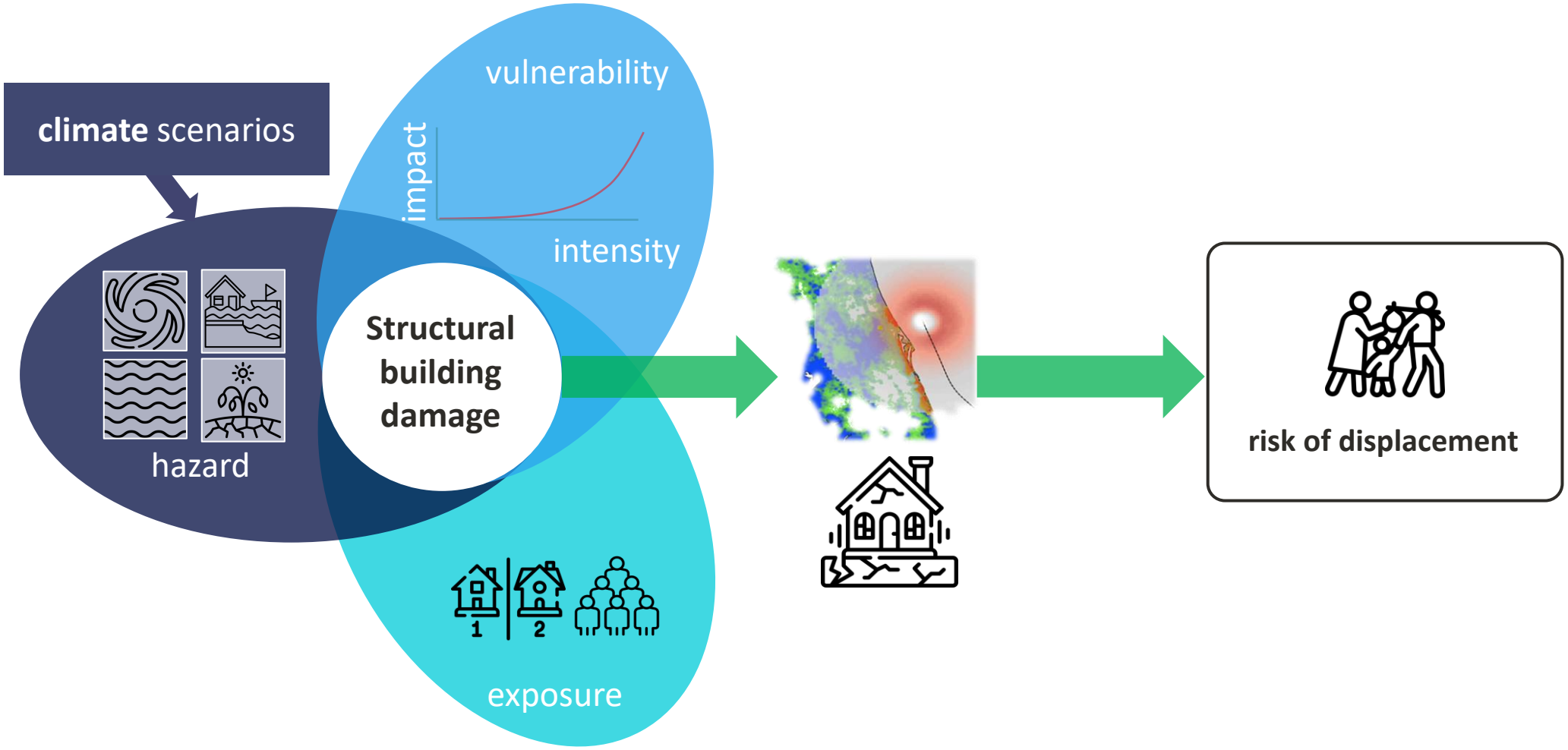
Stanford University

Displacement risk

# *Collaborations and project setup*

- **iDMC** (internal displacement monitoring center) & **UNU** (United Nations University, Bonn)
  - UNU-EHS (Drought)
  - Cima Foundation (River flood)
  - Nanyang Technological University, Singapore (Coastal flood)
  - ETH (Tropical cyclone; global disaster displacement risk model in CLIMADA)

# *Global displacement risk modeling*




Meiler et al. (2025), *in review*

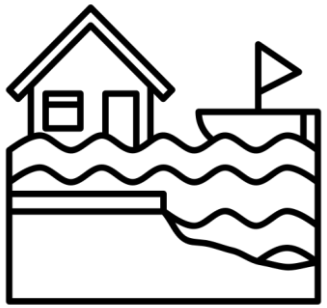
Global displacement risk model

# *Hazards*

tropical cyclones

Emanuel (2006, 2008)

coastal floods



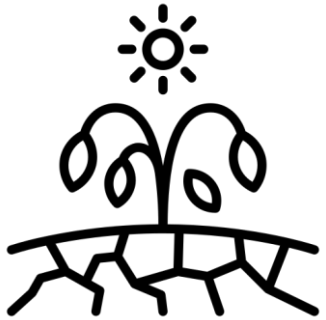
Kasmalkar et al. (2024)

river floods

CIMA

Rossi et al. (2024)

drought



UNU-EHS

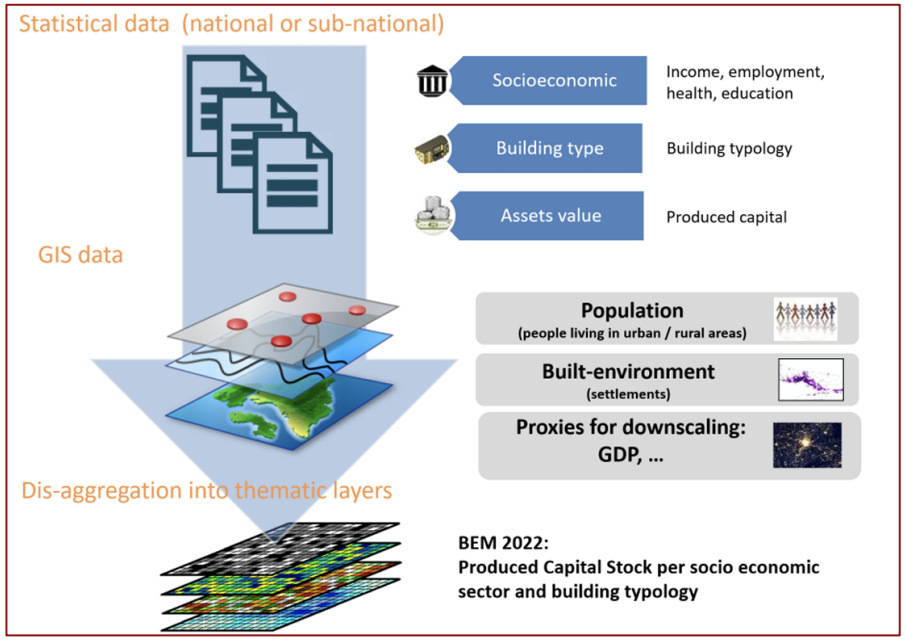
Global displacement risk model

# *Exposure – BEM (building exposure model)*







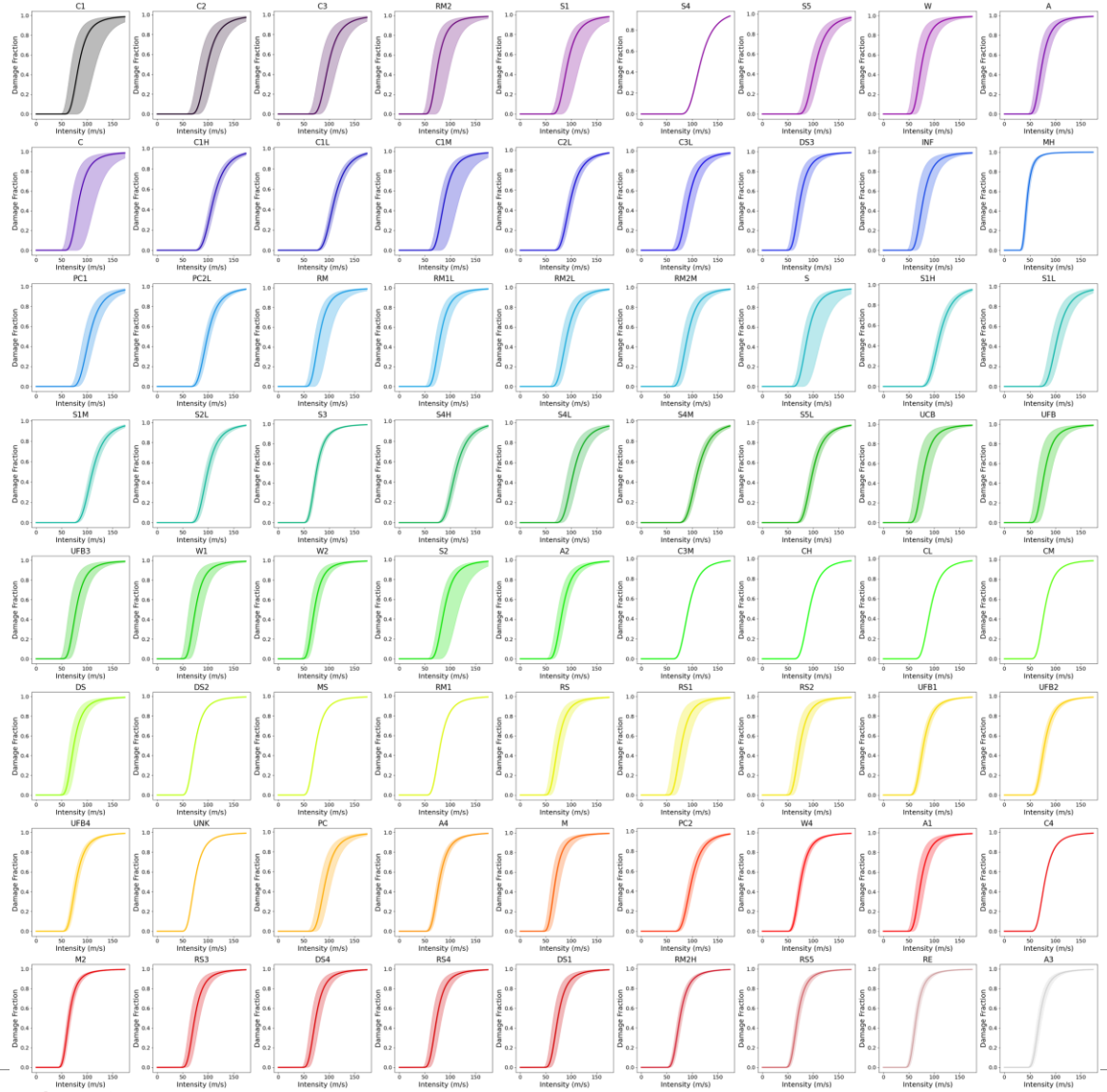




Piller et al. (2023), UNEP-GRID

global geo-spatial exposure layer(s)

Global displacement risk model

# *Vulnerability – mapping CAPRA functions to the BEM layer*

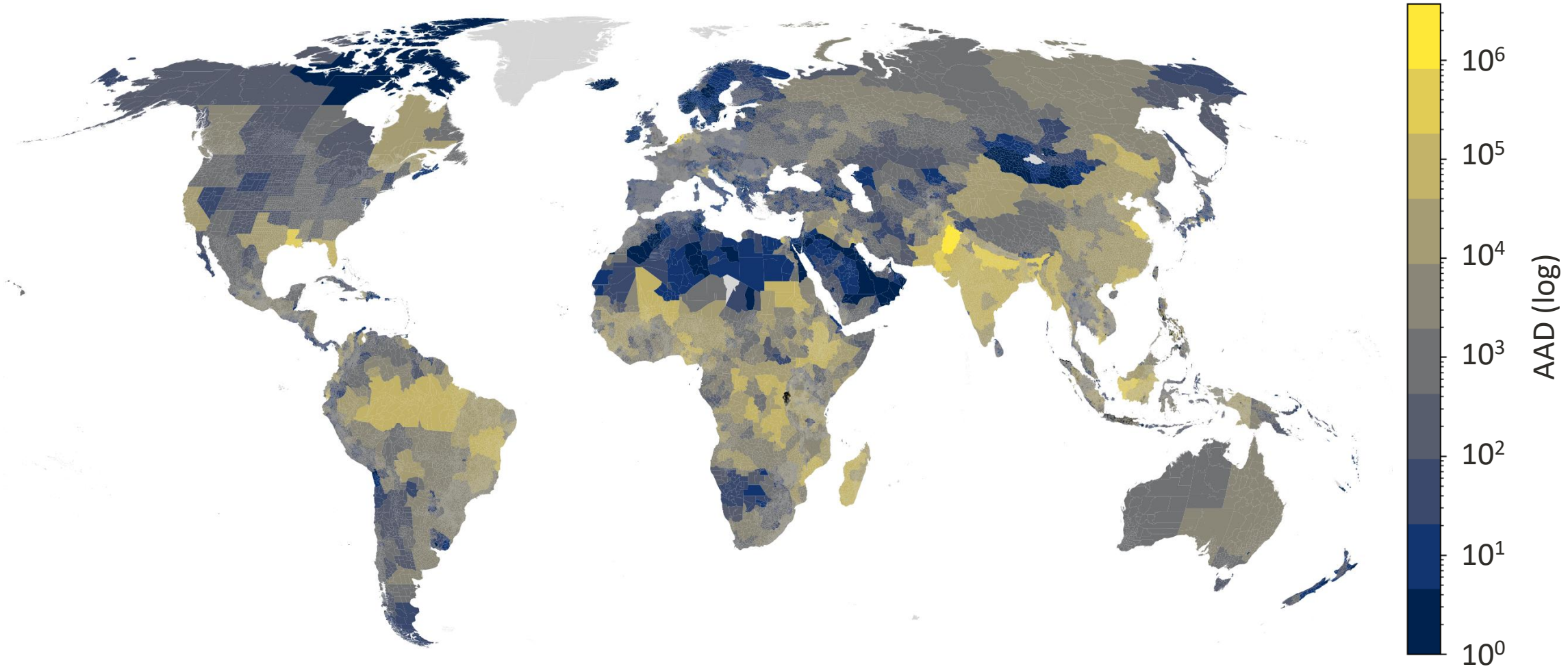



Vulnerability functions per building type

- Pager building types → classes
- Function per class (72 TC, 15 CF)
- Choice of displacement threshold: 30%, **55%**, 70%

Global displacement risk modeling

# *Results: Admin1 level totals*



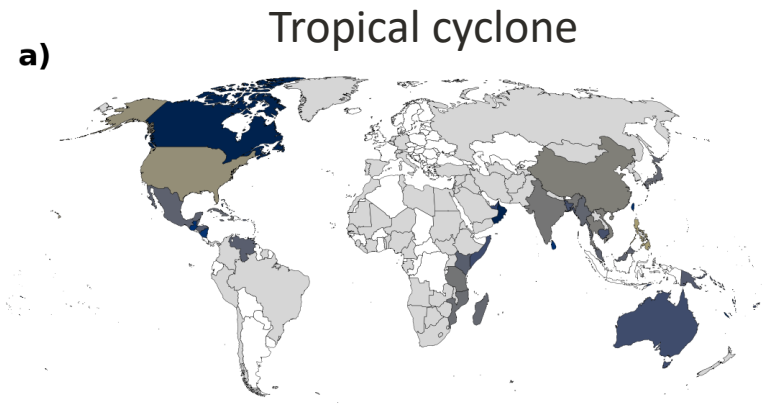

AAD = Annual Average Displacement

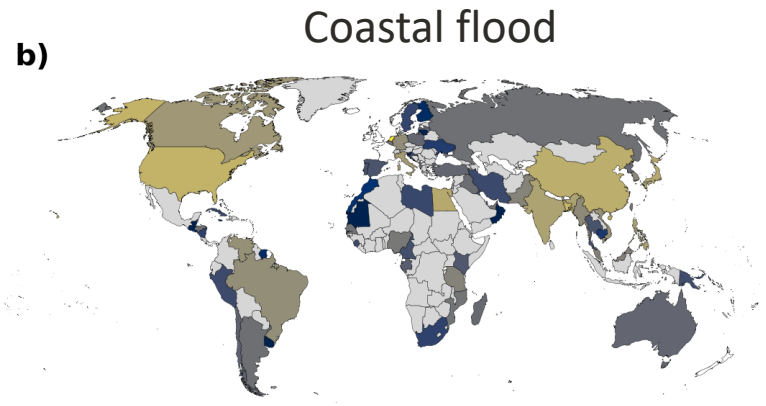
Meiler et al. (2025), *in review*

Global displacement risk modeling

# *Results: Single hazard perspective*

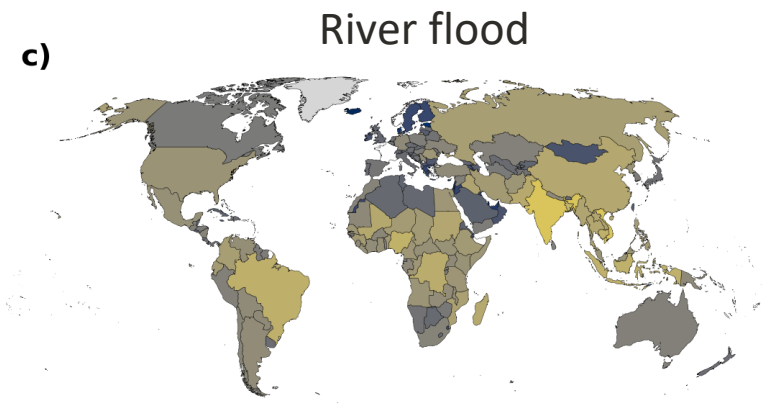
170’000

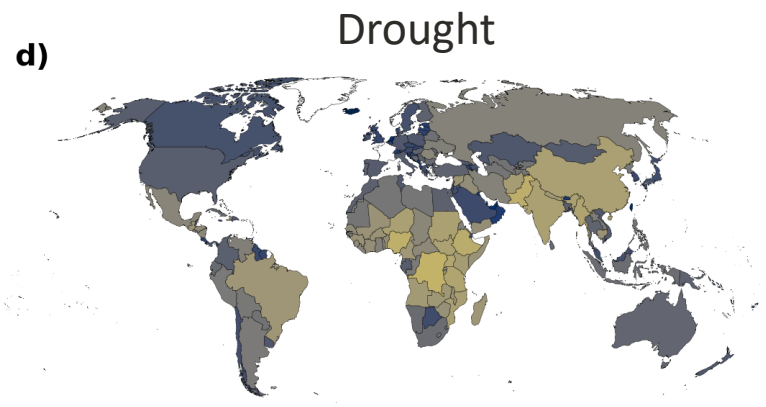


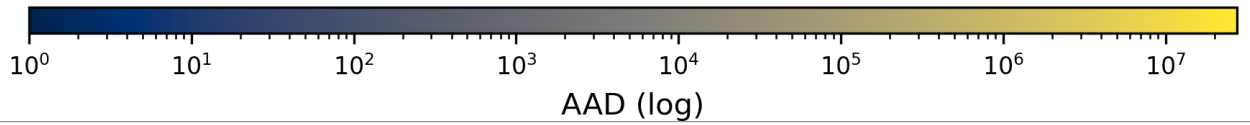

10 million

12 million




4.7 million



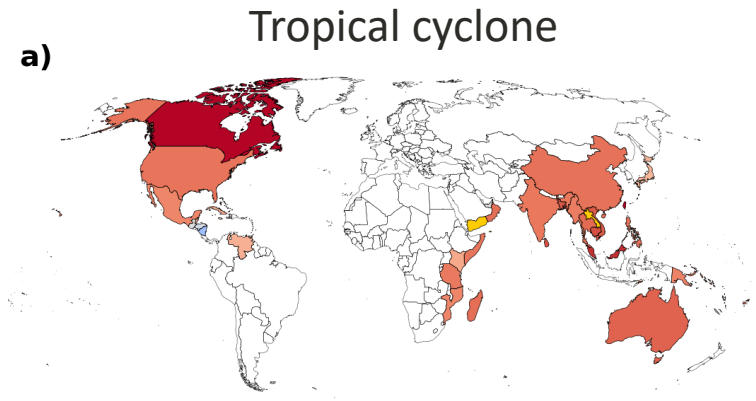

Meiler et al. (2025), *in review*

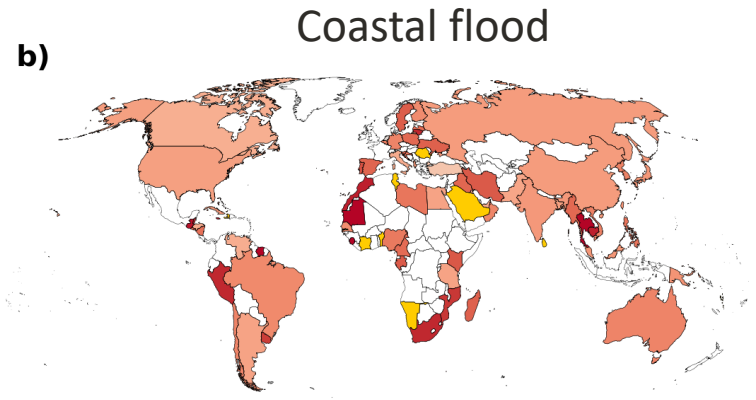
AAD = Annual Average Displacement

Global displacement risk modeling

# *Results: Future displacement risk change by 2100 optimistic scenario*

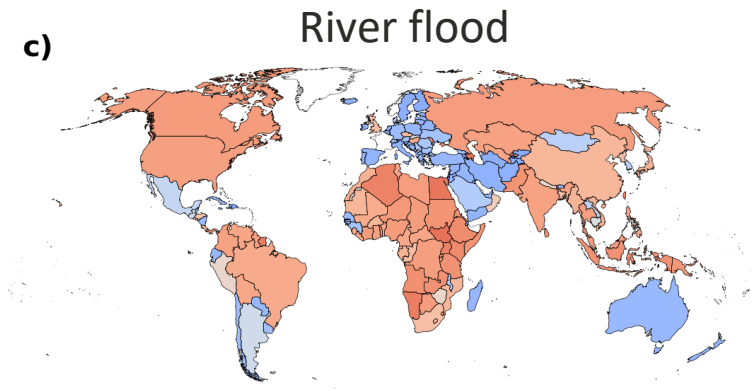
+ 485%
(+ 948%)

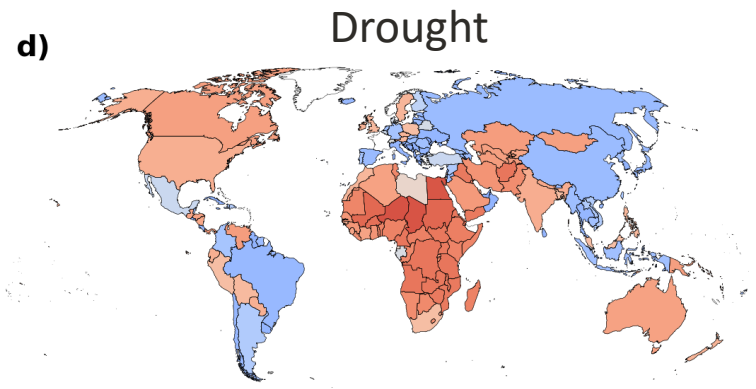


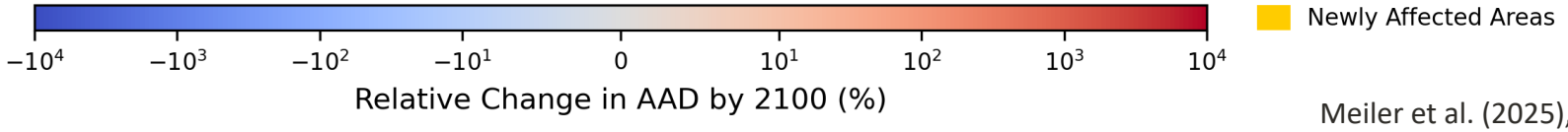

+ 39%
(+ 97%)

+ 46%
(+ 111%)



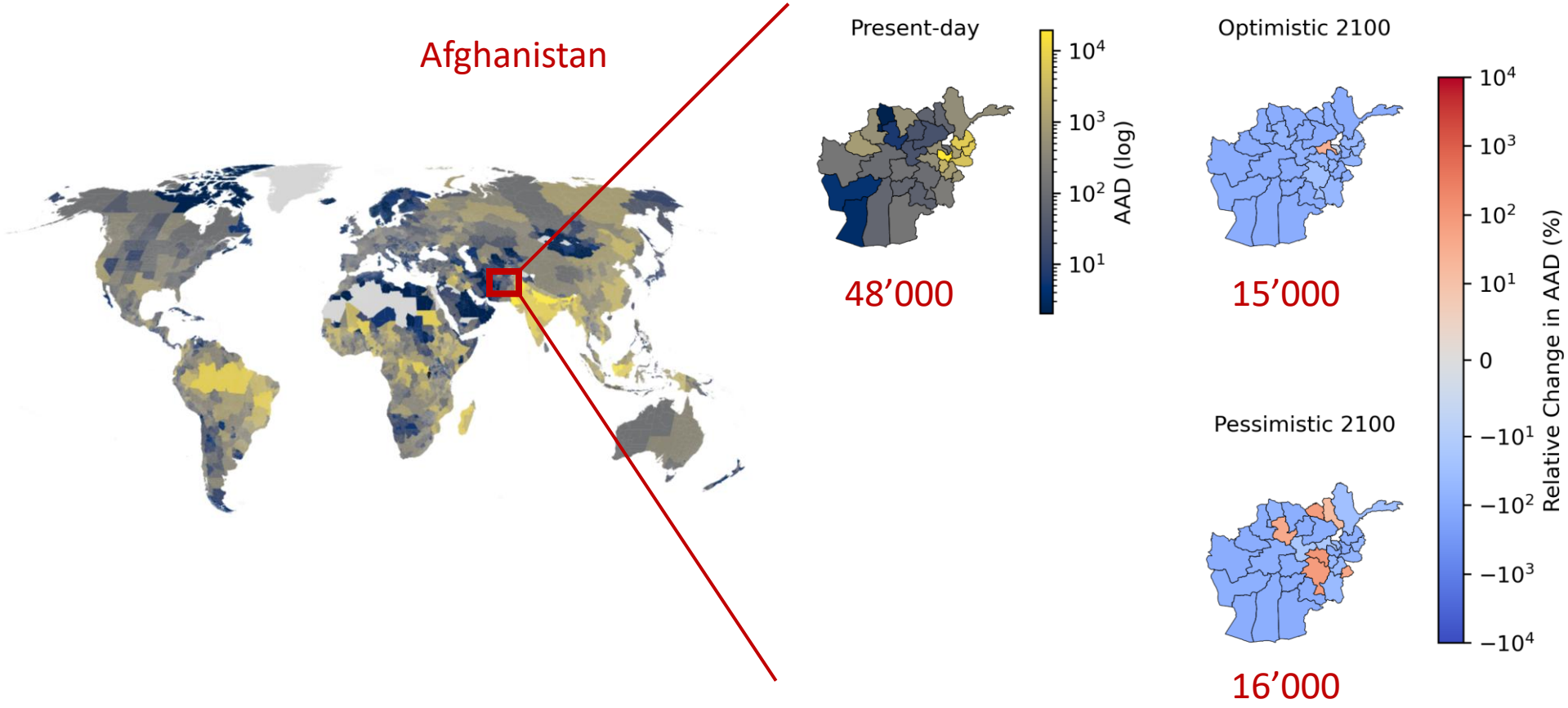

+ 292%
(+ 521%)




Meiler et al. (2025), *in review*

Global displacement risk modeling

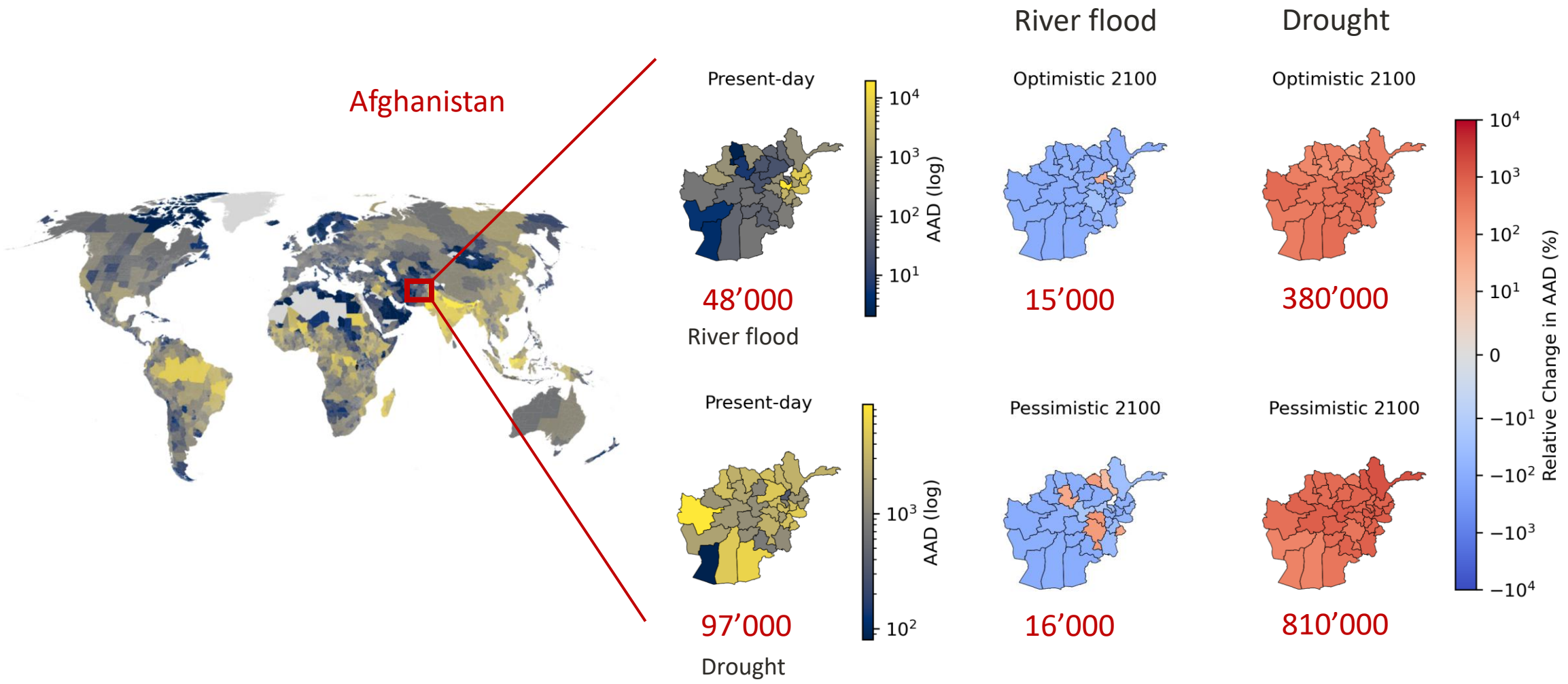
# *Results: Regional analysis Afghanistan – river floods*




Meiler et al. (2025), *in review*

Global displacement risk modeling

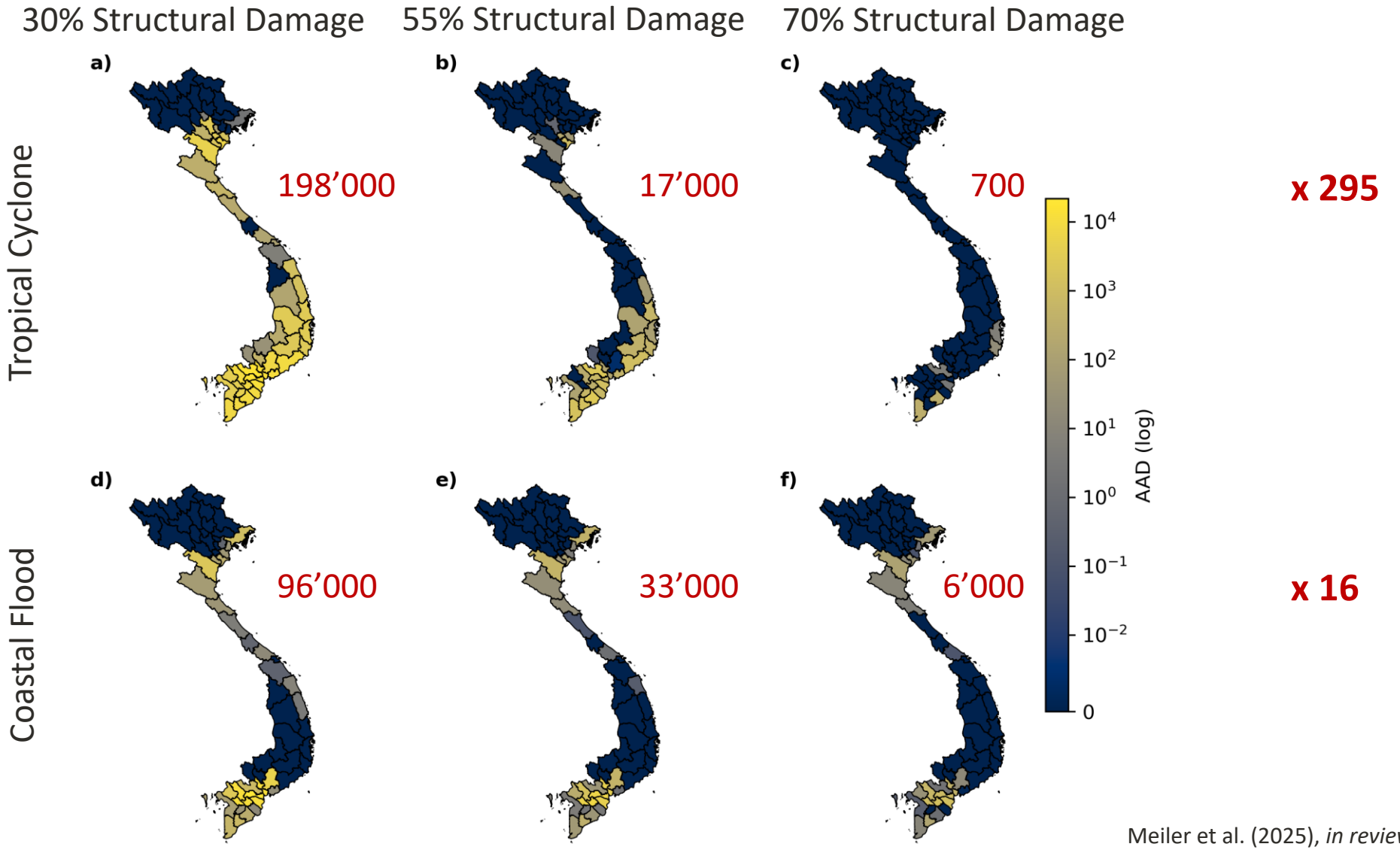
# *Results: Regional analysis Afghanistan – river floods & droughts*




Meiler et al. (2025), *in review*

Global displacement risk modeling

# *Results: Sensitivity analysis building damage threshold*




Meiler et al. (2025), *in review*

# *Frontiers & Challenges*

- Summary
  - forward-looking, risk informed approach to displacement
  - modular, open-source, transparent modelling chain
- Key challenges
  - *arbitrary choices* for **thresholds**, choice of impact functions
  - displacement solely based on **loss of home** (at least for TC and CF)
  - model **evaluation** versus short observational time series
  - **data quality** (e.g. BEM may have outdated population counts)
- Outlook/future research agenda
  - incorporating modulating factors (social, political, environmental, demographic, economic)
  - more hazards
  - assessing costs associated with displacement → loss and damage

# The relationship between extreme weather events and support for climate policies


Stanford University

# *Extreme weather events and global climate policy support*

## Social science:

Lead: Viktoria Cologna

ETH Zurich, Collegium Helveticum, Harvard University

Method: Global survey data in **68 countries**; **N=71’922**

Trust in Science and Science-related Populism (TISP) Many Labs study *(Cologna et al., 2025, Nat. Human Behav.)*

## Natural science:

Lead: Simona Meiler

Method: CLIMADA; population exposure to **7 extreme event categories** in 68 countries

- *River floods*
- *Heatwaves*
- *European winter storms*
- *Tropical cyclones*
- *Wildfires*
- *Heavy precipitation*
- *Droughts*

Cologna, Meiler, et al. (2025), *resubmitted*

# *Extreme weather events and global climate policy support*

## Social science:

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Method: Global survey data in **68 countries**; **N=71’922**

Trust in Science and Science-related Populism (TISP) Many Labs study *(Cologna et al., 2025, Nat. Human Behav.)*

People who **attribute** extreme weather events to climate change or who lived in countries with higher **exposure** show stronger **support for climate policies**

## Natural science:

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Method: CLIMADA; population exposure to **7 extreme event categories** in 68 countries

- *River floods*
- *Heatwaves*
- *European winter storms*
- *Tropical cyclones*
- *Wildfires*
- *Heavy precipitation*
- *Droughts*

Cologna, Meiler, et al. (2025), *resubmitted*

Research question 1

*Extreme weather events and global climate policy support*

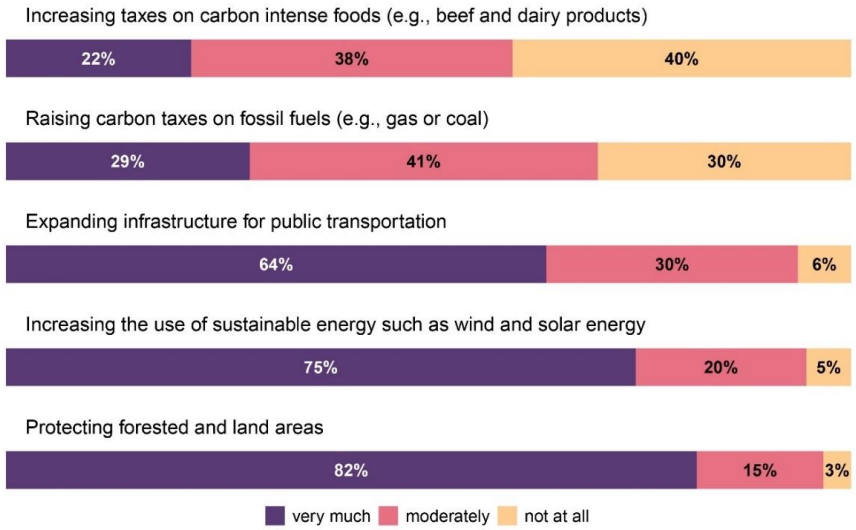
What is the **level of public support** for five climate policies across countries?

Cologna, Meiler, et al. (2025), *resubmitted*

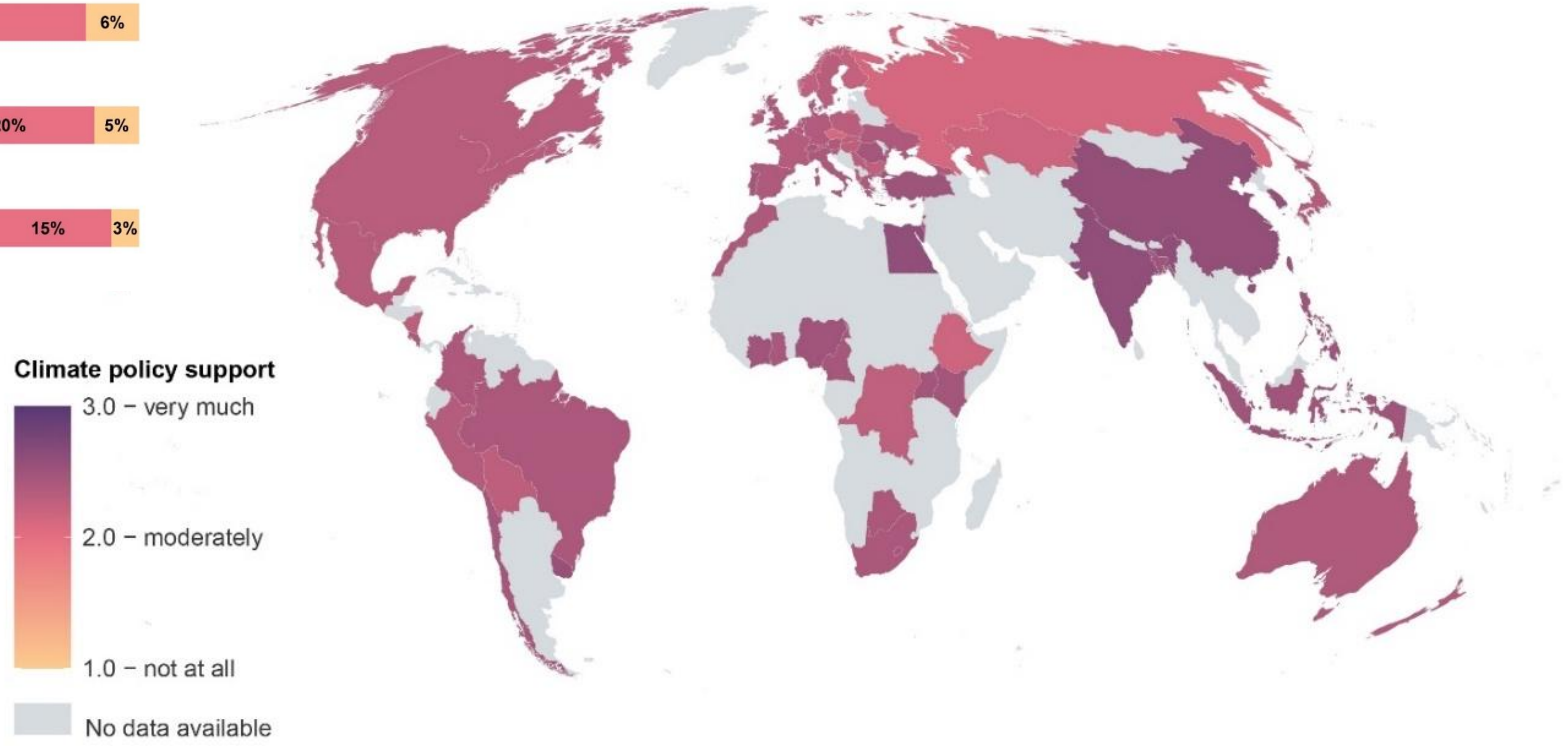
Survey results

# *Climate policy support*

**1a. Weighted response probabilities for single items measuring support for climate policies**




**1b. Mean support for climate policies**




Cologna, Meiler, et al. (2025), *resubmitted*

Research question 2

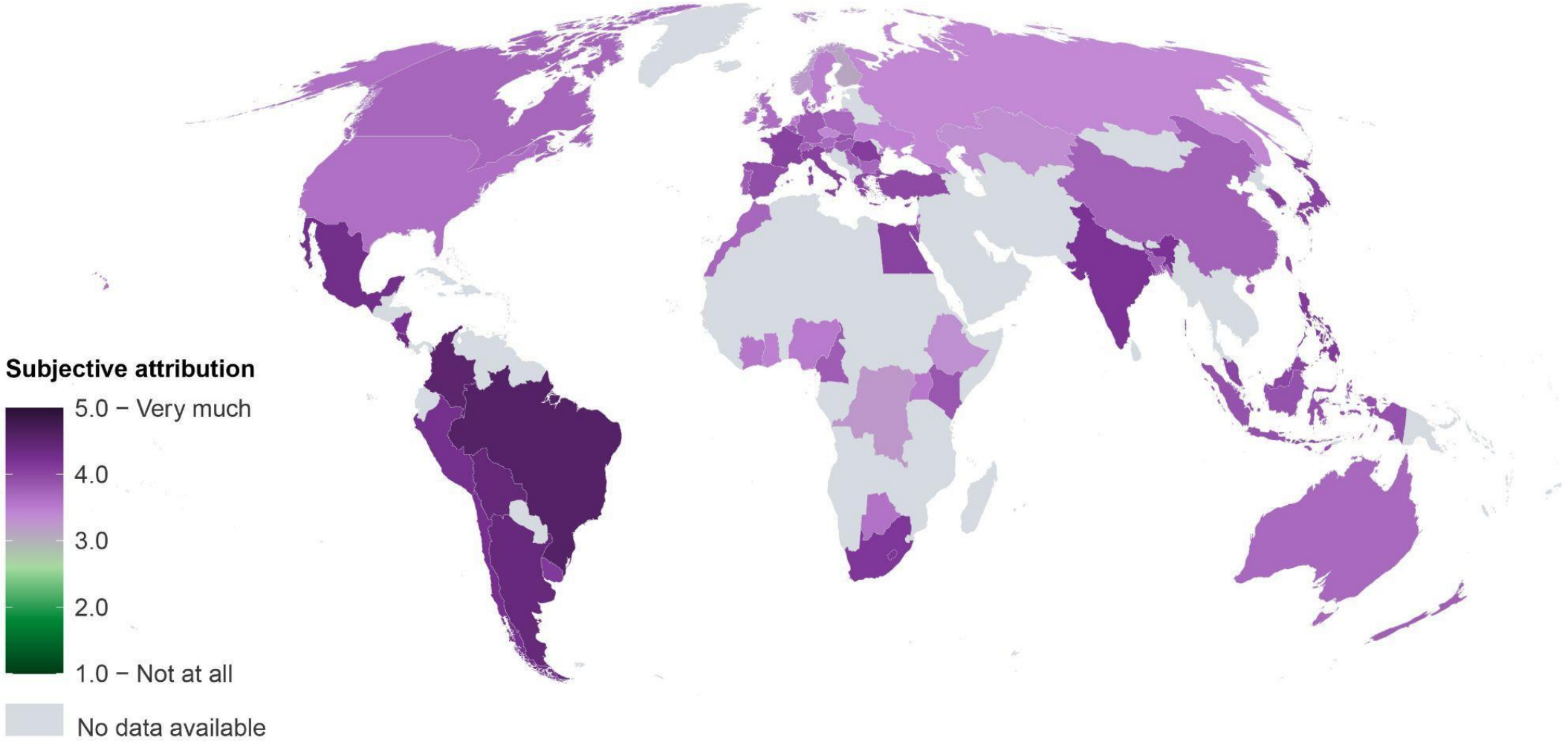
*Extreme weather events and global climate policy support*

To what degree do people **attribute extreme weather events to climate change** across countries (subjective attribution) and **is subjective attribution related to policy support?**

Cologna, Meiler, et al. (2025), *resubmitted*

Survey results

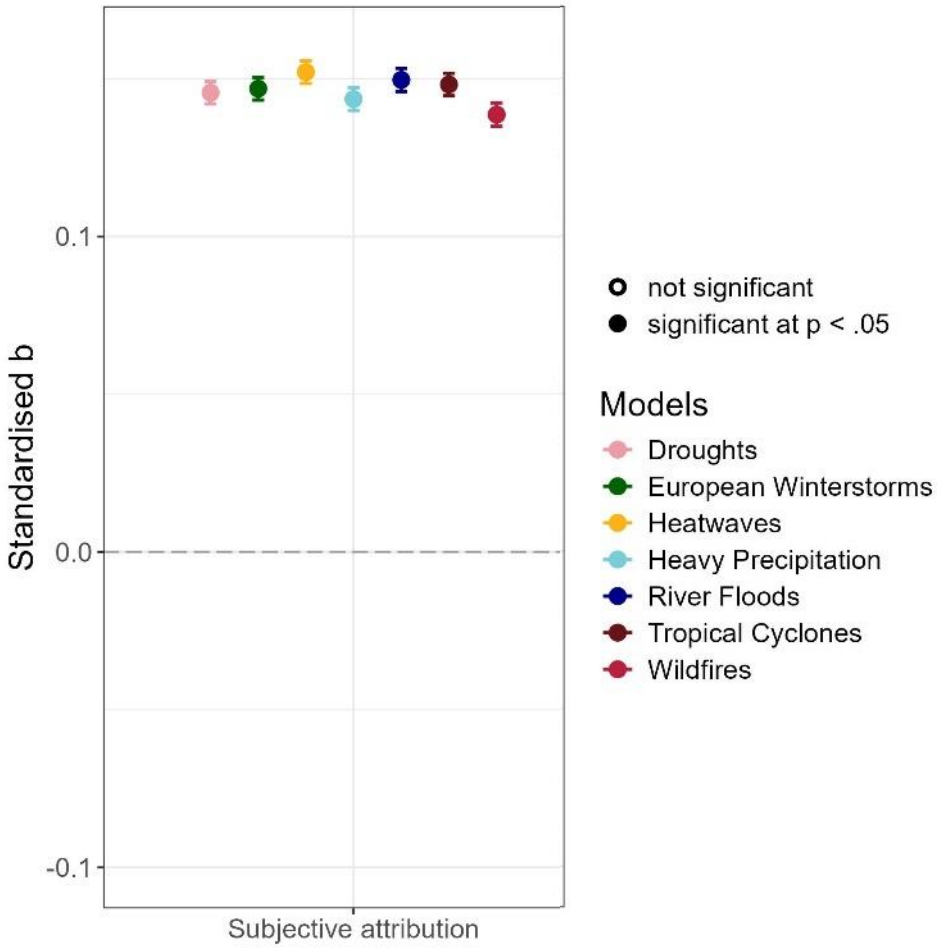
# *Subjective attribution of extreme weather events to climate change*




Cologna, Meiler, et al. (2025), *resubmitted*

Model output

# *Does subjective attribution predict climate policy support?*




Cologna, Meiler, et al. (2025), *resubmitted*

Research question 3

*Extreme weather events and global climate policy support*

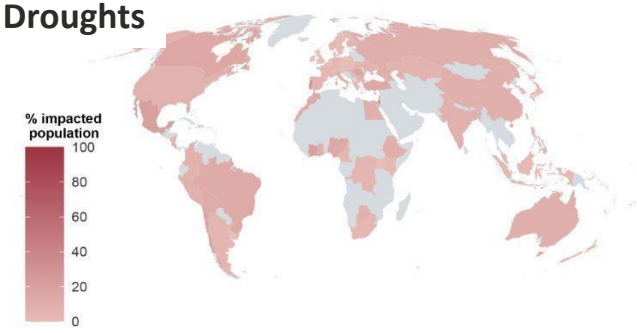
Does **exposure to extreme weather events** on the population level relate to policy support?

Cologna, Meiler, et al. (2025), *resubmitted*

Model output

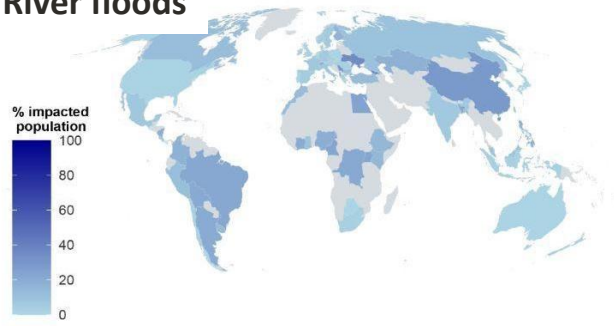
# *Exposed population to extreme weather events*

**Droughts**

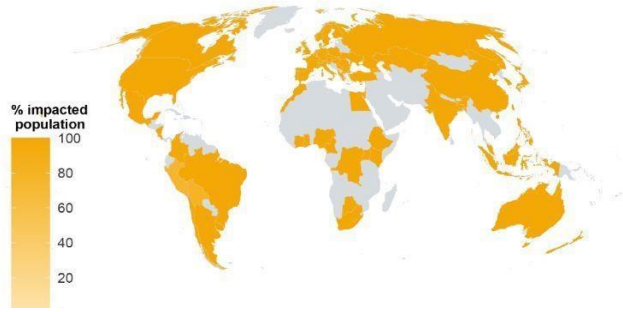



**European Winterstorms**


**River floods**

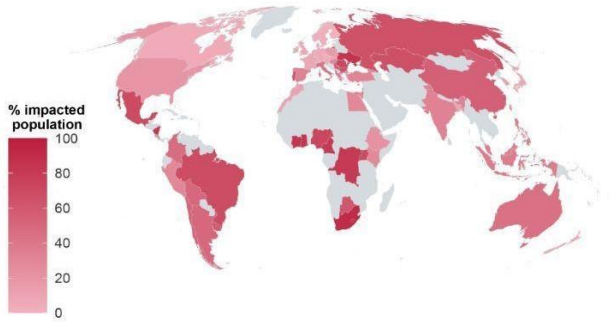



**Heatwaves**

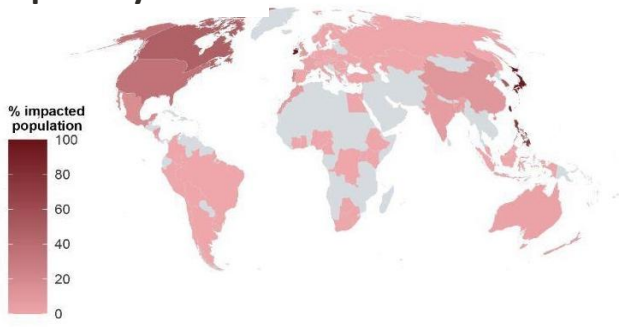



**Heavy precipitation**


**Wildfires**



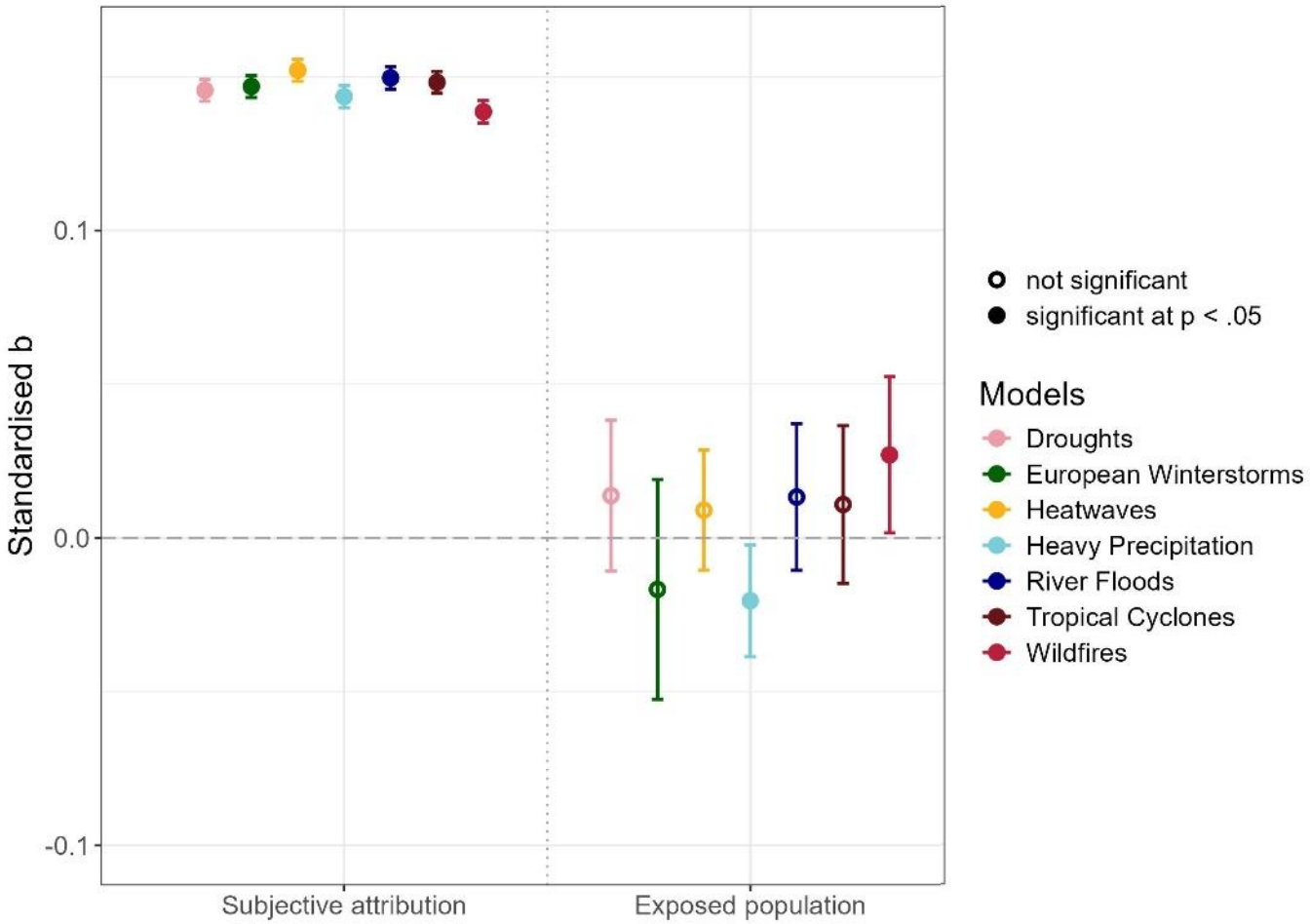

**Tropical Cyclones**




Cologna, Meiler, et al. (2025), *resubmitted*

Model output

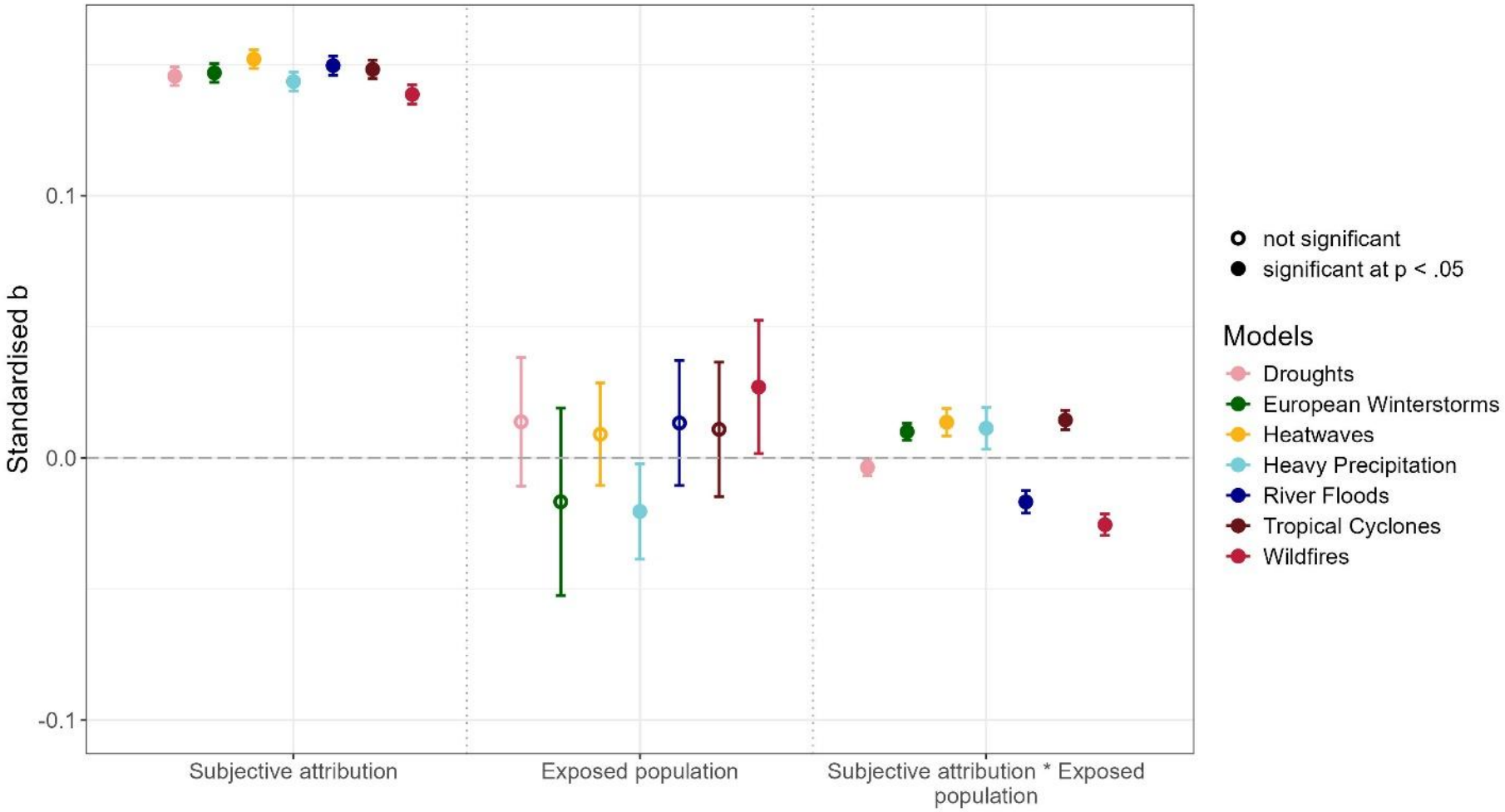
# *Does exposure to extreme weather events predict climate policy support?*




Cologna, Meiler, et al. (2025), *resubmitted*

Model output

# *Interactive effect of subjective attribution and exposed population*




Cologna, Meiler, et al. (2025), *resubmitted*

Discussion

# *Key findings & implications*

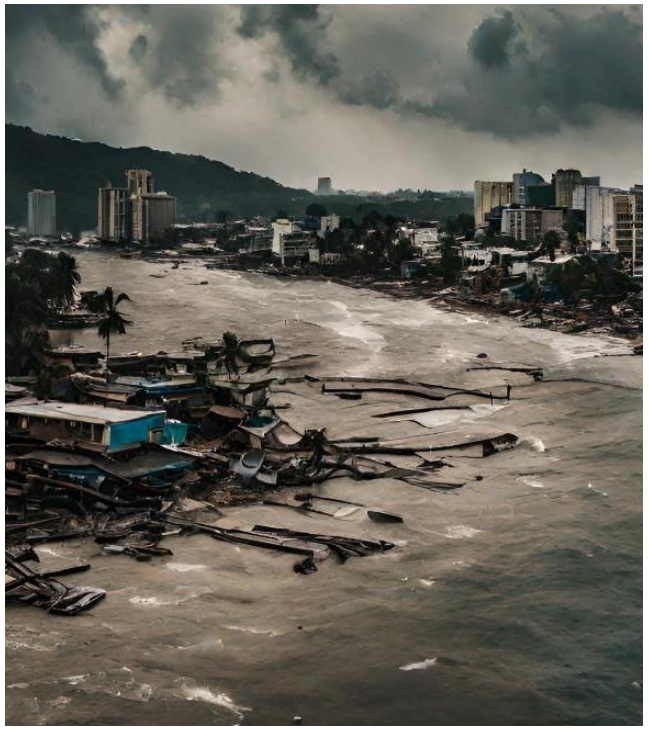
- Hypothesis:
  Stronger climate policy support from:
  - People who **attribute** extreme weather events to climate change ✓
  - or who lived in countries with higher **exposure** ✗

  ⟶ Communication strategies to increase subjective attribution & climate policy support
- Outlook:
  - Temporal proximity
  - Extreme event severity

Cologna, Meiler, et al. (2025), *resubmitted*

Advancing climate risk assessment

# *Tropical Cyclones, Displacement, and Policy*



# Thank you!

**smeiler@stanford.edu**