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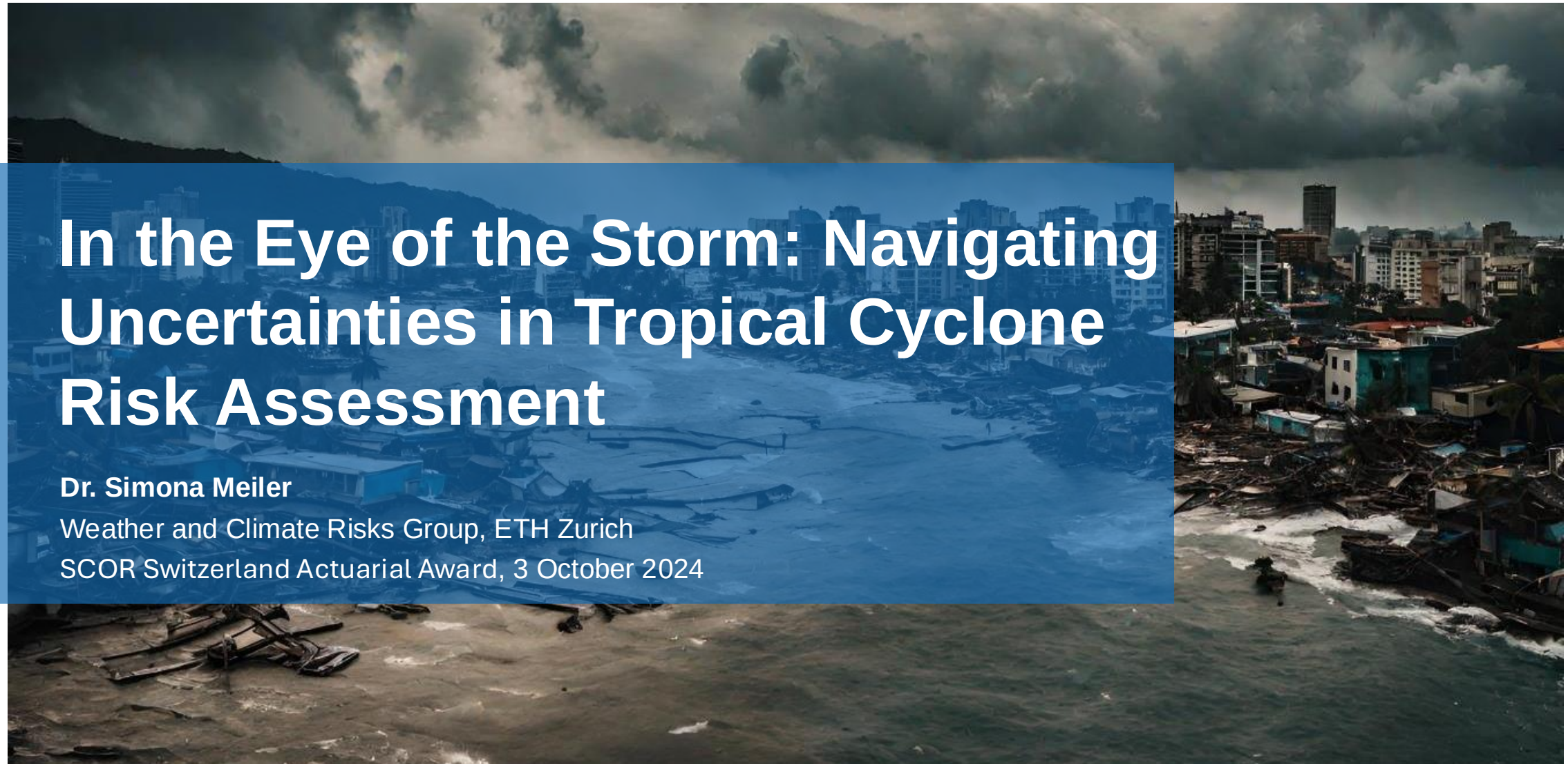


In the Eye of the Storm: Navigating Uncertainties in Tropical Cyclone Risk Assessment

Dr. Simona Meiler
Weather and Climate Risks Group, ETH Zurich
SCOR Switzerland Actuarial Award, 3 October 2024

Tropical cyclones cause devastating impacts

Hurricane Ian

Ricardo Arduengo/AFP via Getty Images

Hurricane Otis

Rodrigo Oropeza / AFP / Getty

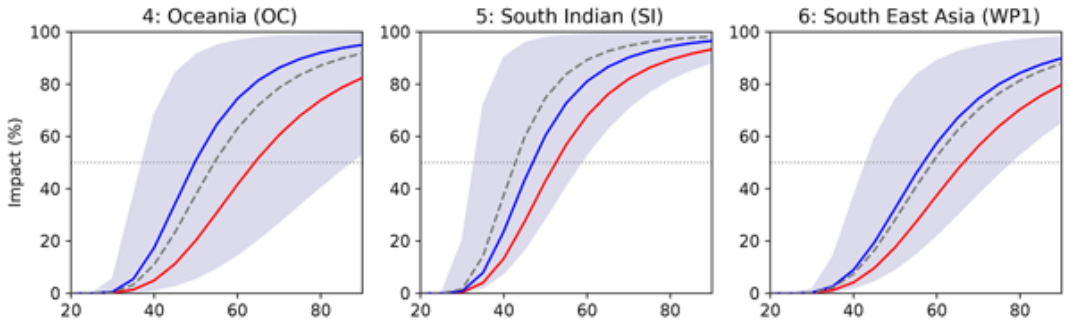
Hurricane Helene

Luis Santana/Tampa Bay Times/ZUMA via Shutterstock

2022 → 2023 → 2024

Introduction

Risk assessment

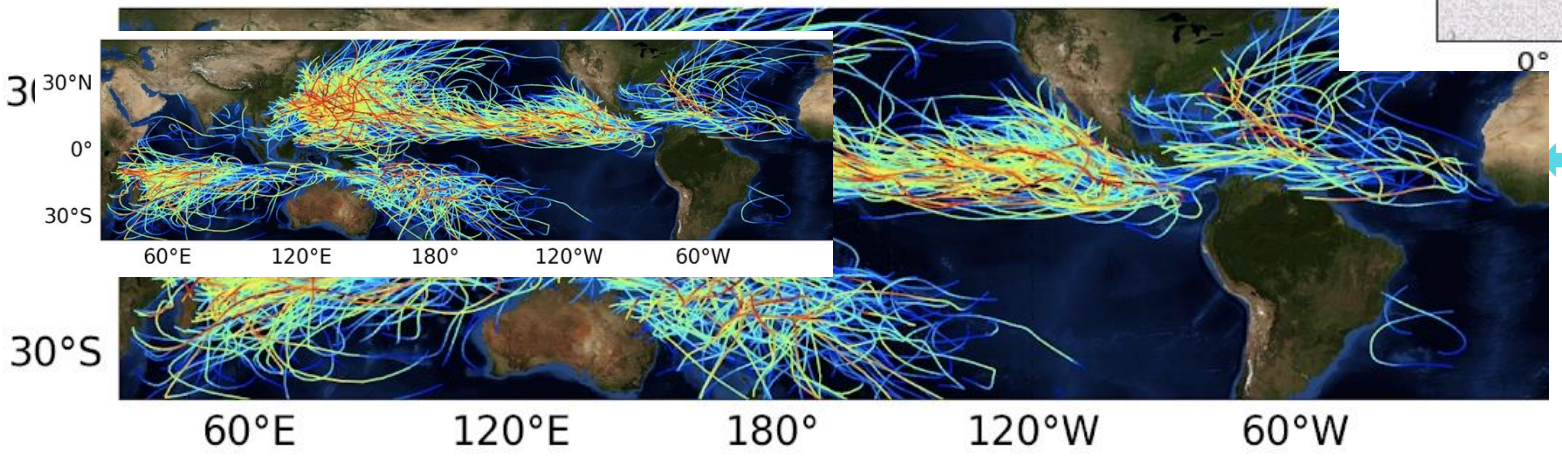


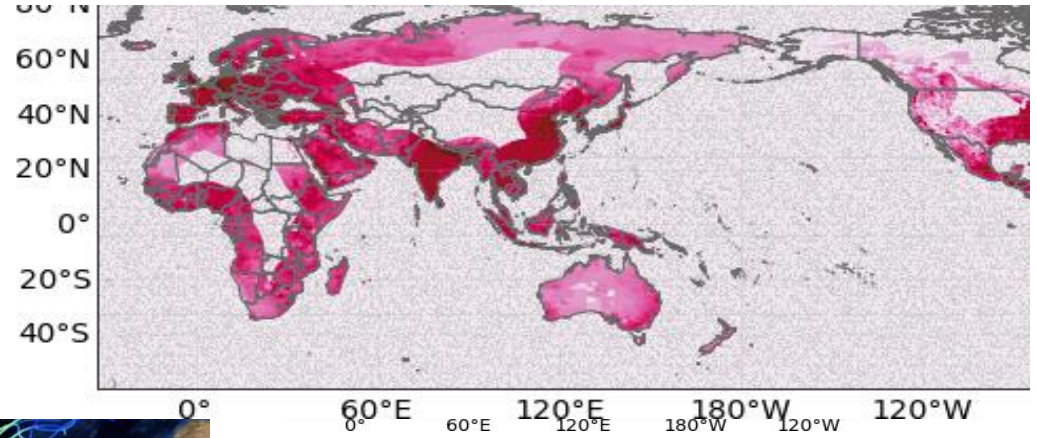
Regionally calibrated impact functions

Climate change

TC hazard sets

CLIMADA
probabilistic event-based simulation
open-source[1]





Spatially explicit asset value

Socio-economic development

[1]Az

Aims and focus of this thesis

What are crucial sources of uncertainty in global tropical cyclone risk assessments?

Specific aims:

I. Tropical cyclone model intercomparison

→ Chapter 2

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

II. Uncertainty & sensitivity analysis for future tropical cyclone risk

→ Chapters 3 & 4

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

III. Synthesis of uncertainty & sensitivity analysis across hazard models

→ Chapter 5

Meiler et al. (2024), *resubmitted*

TC model intercomparison

Risk model setup

TC track sets:

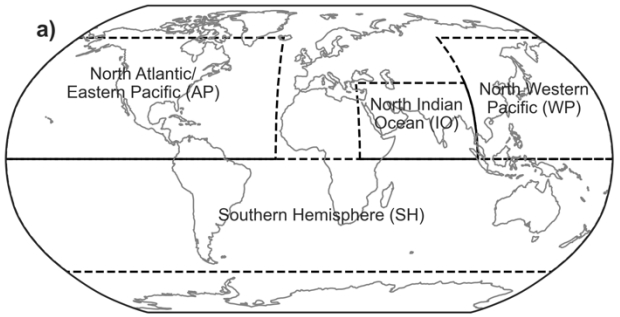
- IBTrACS[1]
- Probabilistic IBTrACS[2]
- STORM[3]
- MIT[4]
- CHAZ[5]

+ wind model[6]

direct economic damage

Present-day TC impacts:

- 1980-2018
- Direct economic damage ($)
  - Expected annual damage (EAD)
  - Return period curves

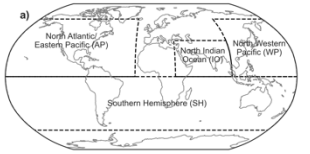


Meiler et al. (2022), *Nature Communications*

[1] Knapp et al. (2010), *BAMS*
[2] Gettelman et al. (2018), *Clim. Chang.*
[3] Bloemendaal et al. (2020), *Sci Rep*
[4] Emanuel et al. (2006, 2008), *BAMS*
[5] Lee et al. (2018), *JAMES*
[6] Holland (2008), *Mon. Weather Rev.*

TC model intercomparison

Results: Expected annual damage (EAD)

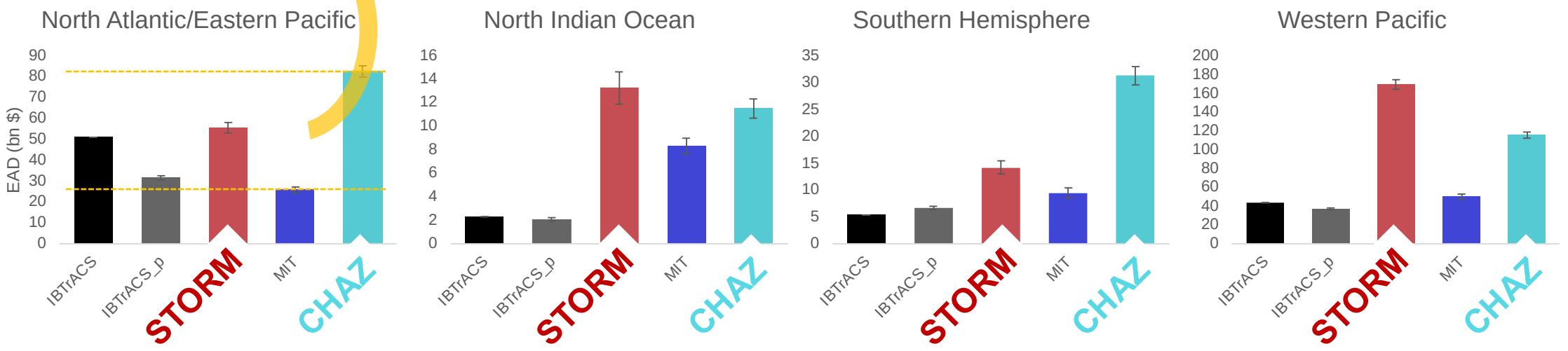


x 3.2

x 6.4

x 5.8

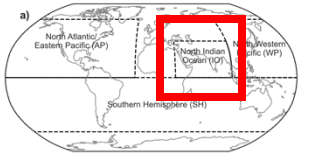
x 4.6

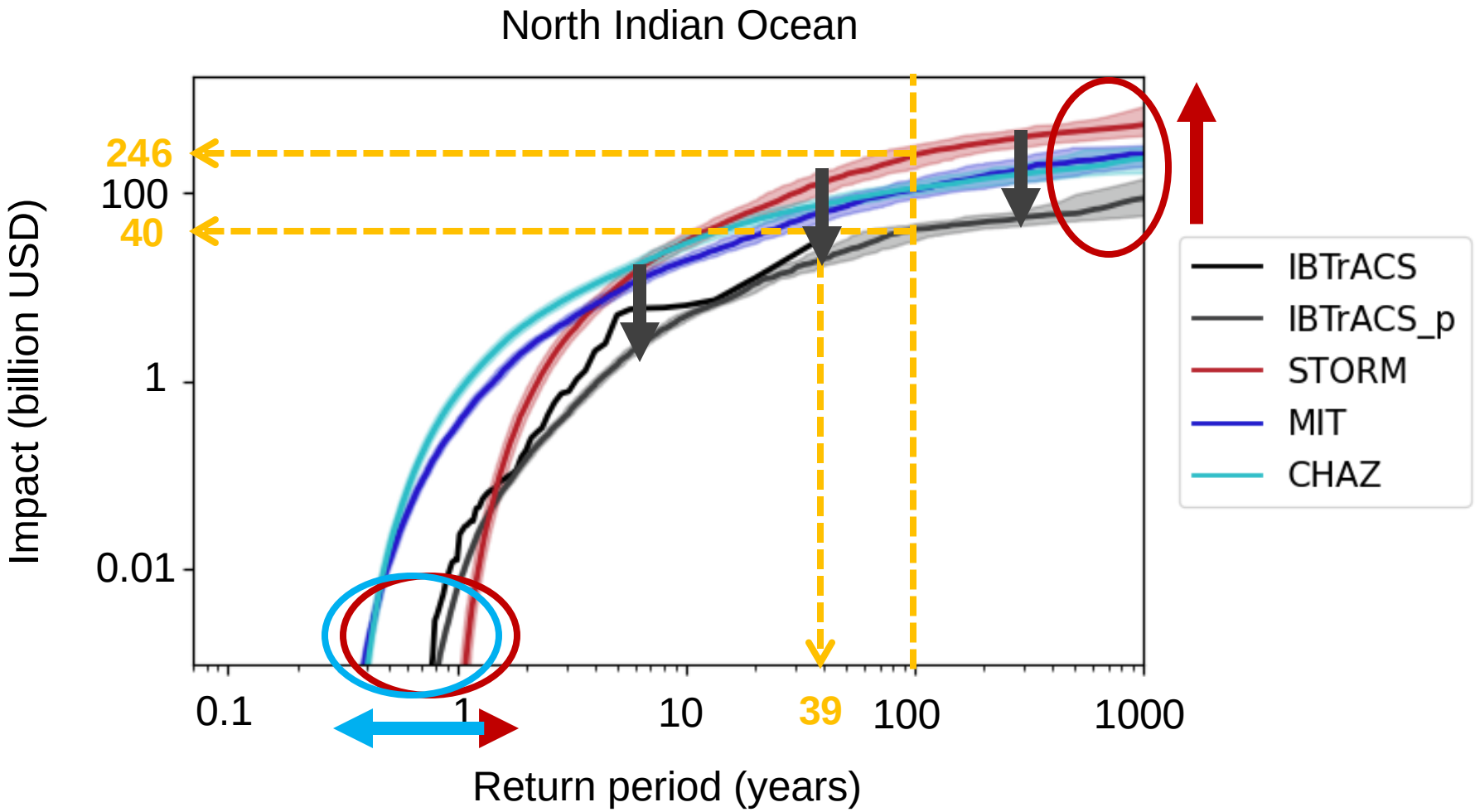


Meiler et al. (2022), *Nature Communications*

TC model intercomparison

Results: Impact return period curves





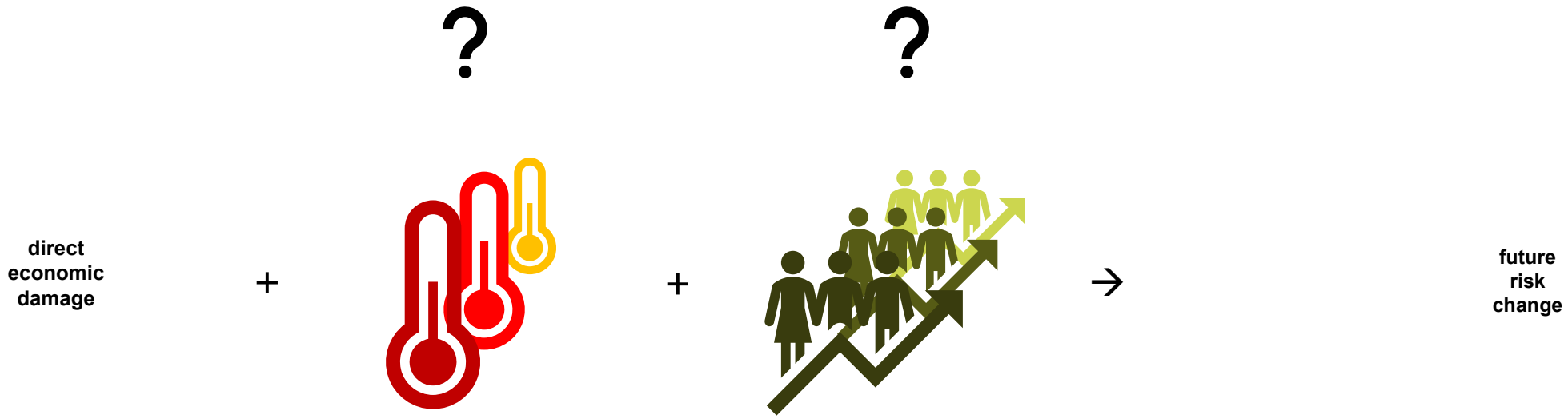
Meiler et al. (2022), *Nature Communications*

Guidance on TC track set choice

quantitative analysis × TC model qualities × application → guidance

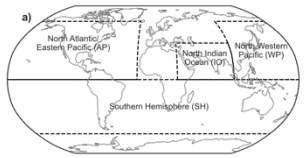
Meiler et al. (2022), *Nature Communications*

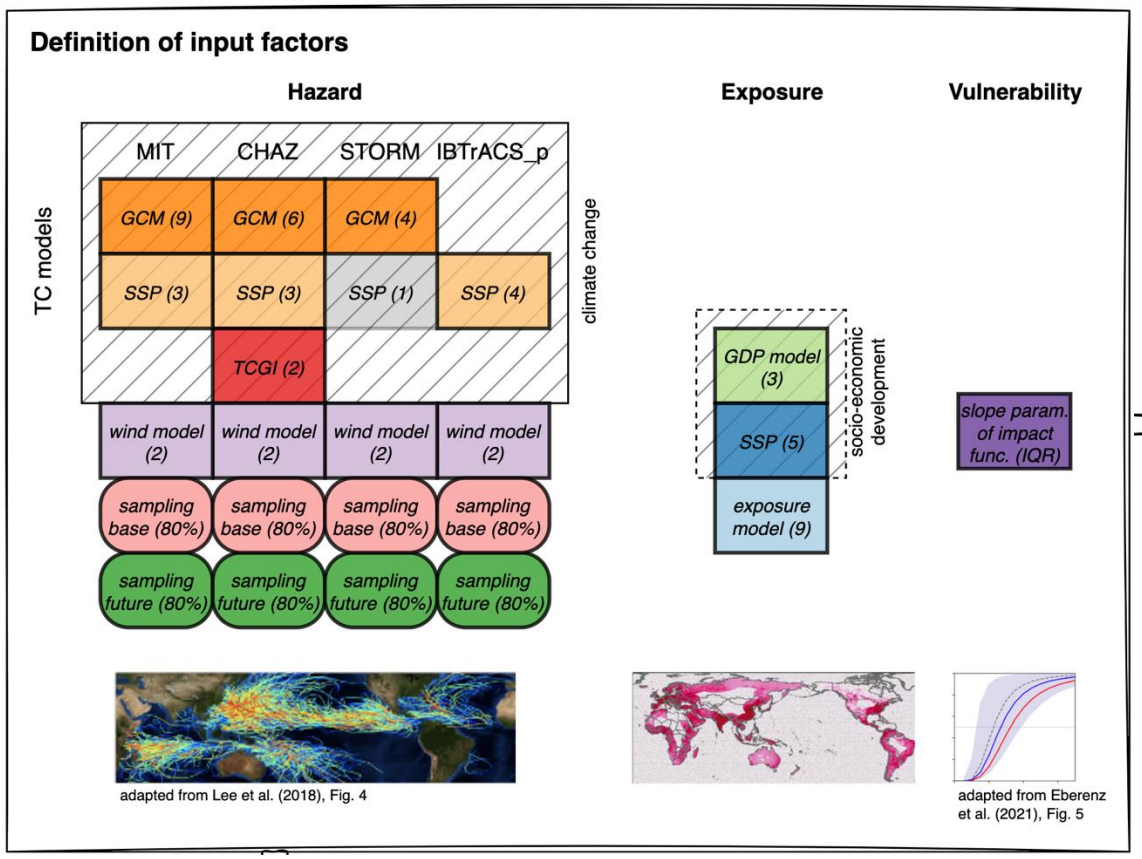
Uncertainties and sensitivities in future TC risk assessment

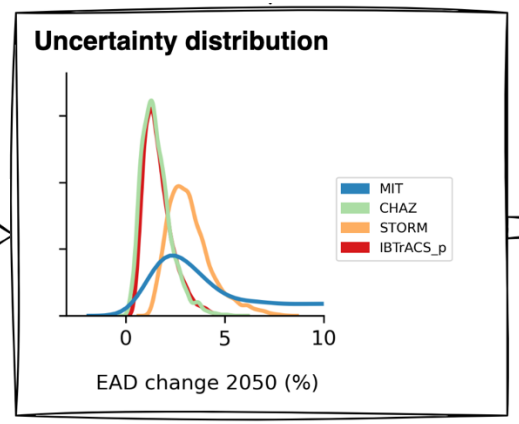


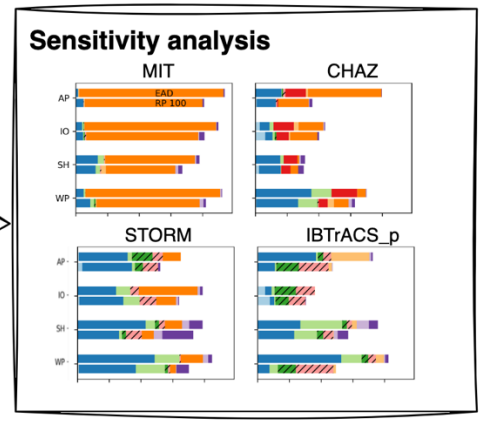
Meiler et al. (2023a), *Comms Earth & Env*
Meiler et al. (2023b), *ICASP14*
Meiler et al. (2024), *resubmitted*

Study setup







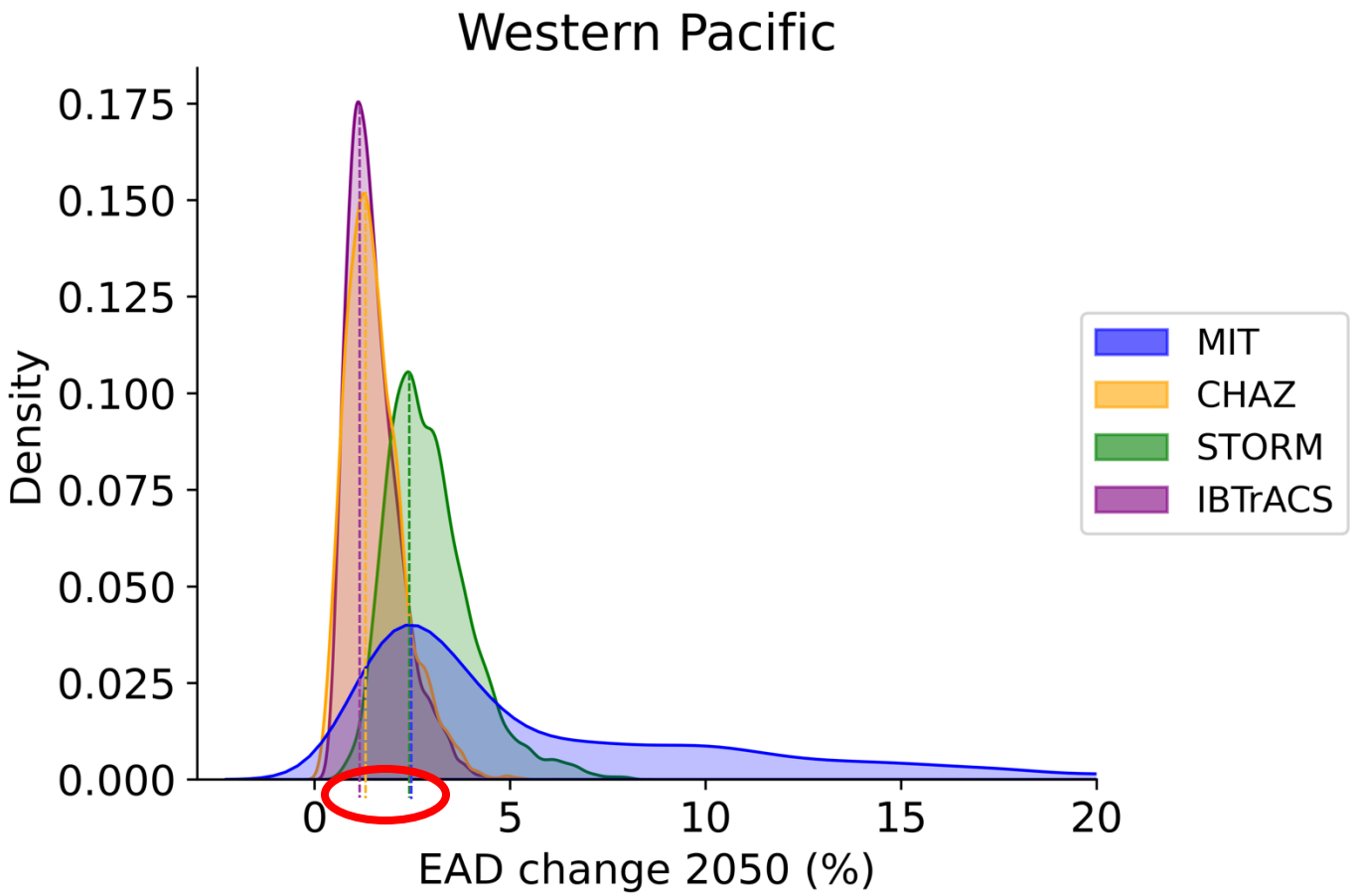


Δ EAD
Δ RP100

N=1024
~ 20’000 input combinations

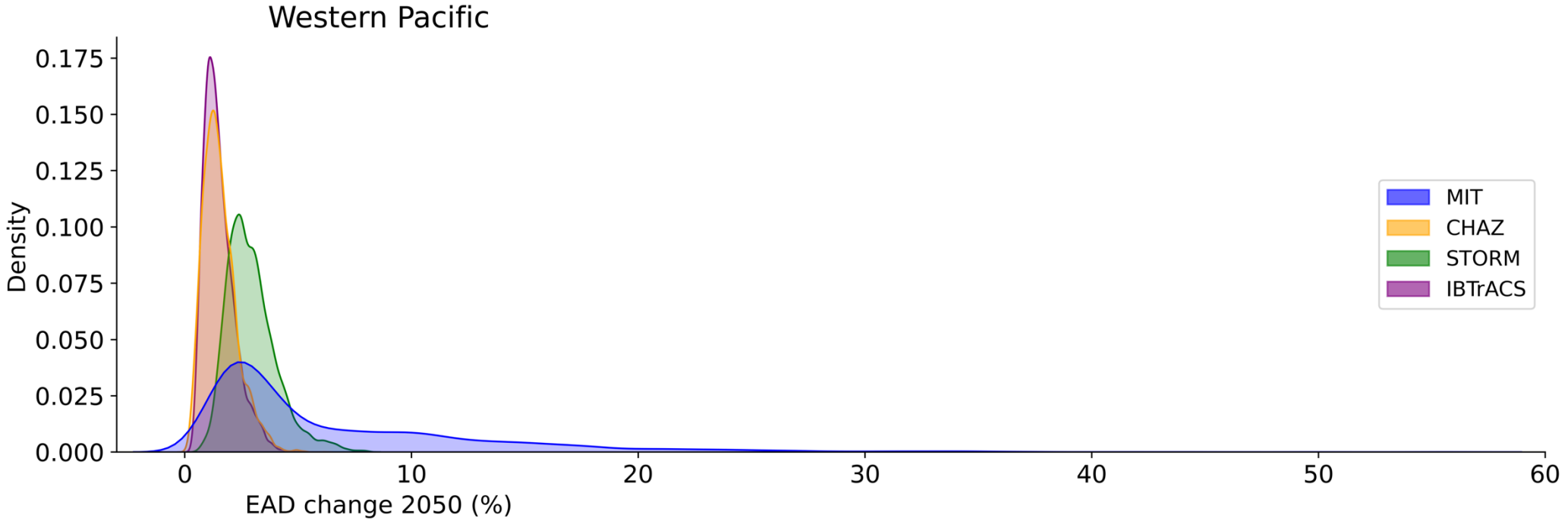
Meiler et al. (2024), *resubmitted*

Results: Uncertainty of future TC risk change



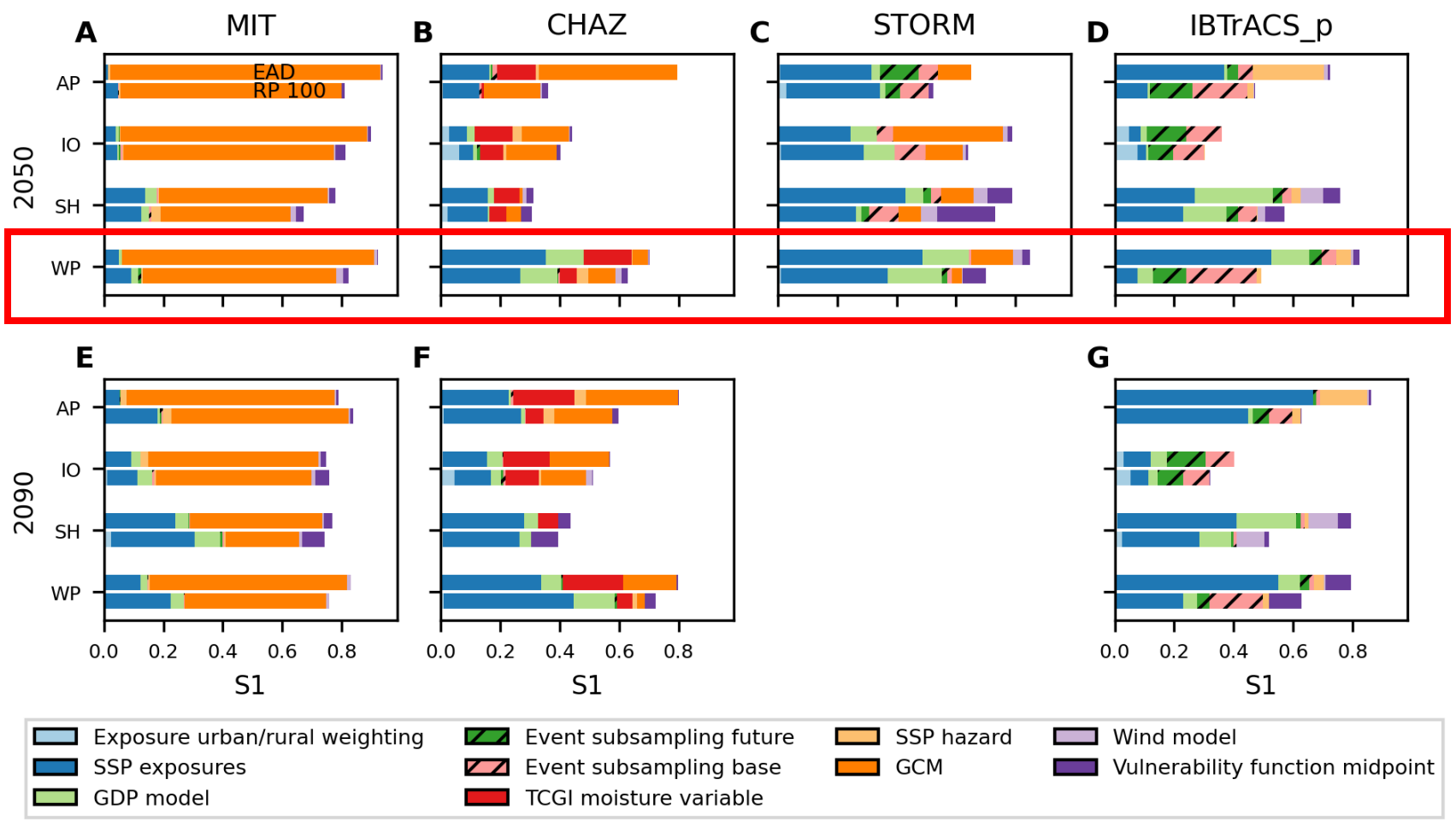
Meiler et al. (2024), *resubmitted*

Results: Uncertainty of future TC risk change



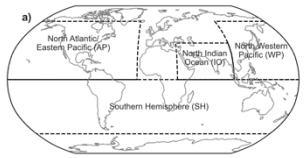
Meiler et al. (2024), *resubmitted*

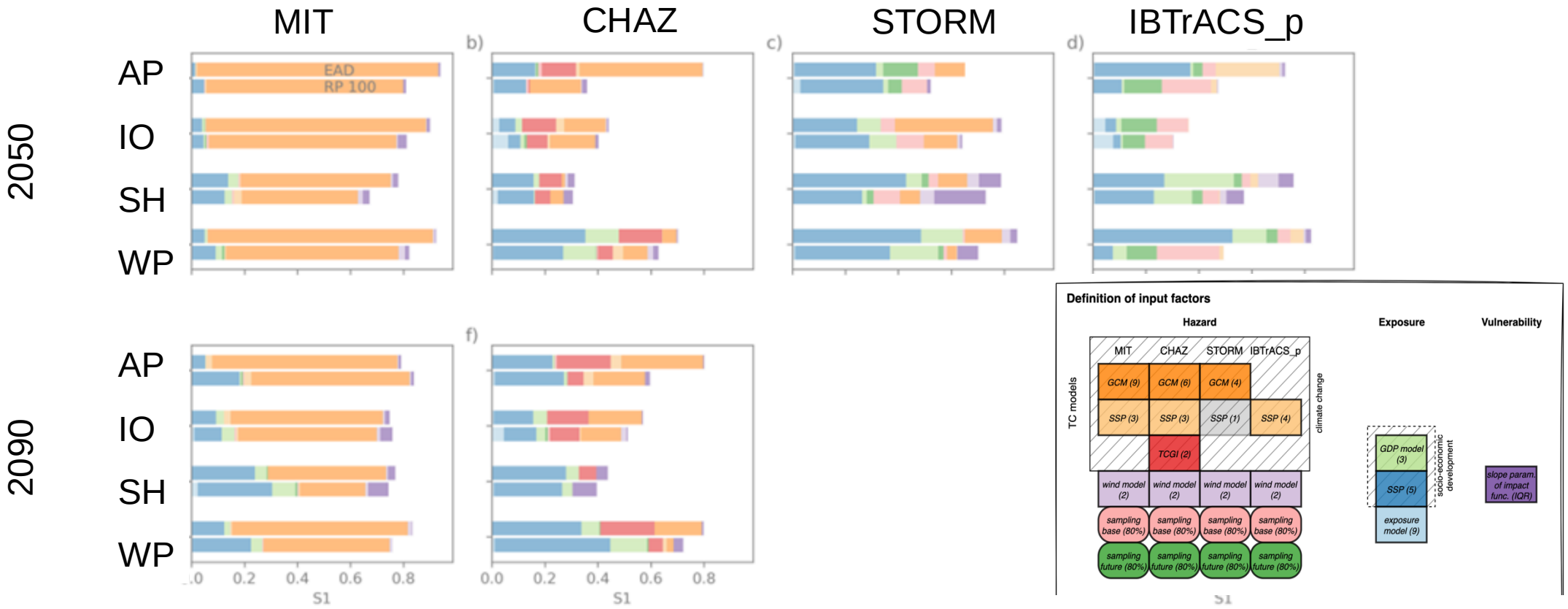
Results: Sensitivity indices



Meiler et al. (2024), *resubmitted*

Results: Sensitivity indices

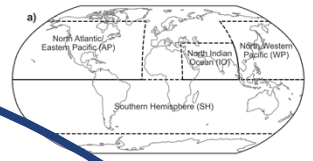


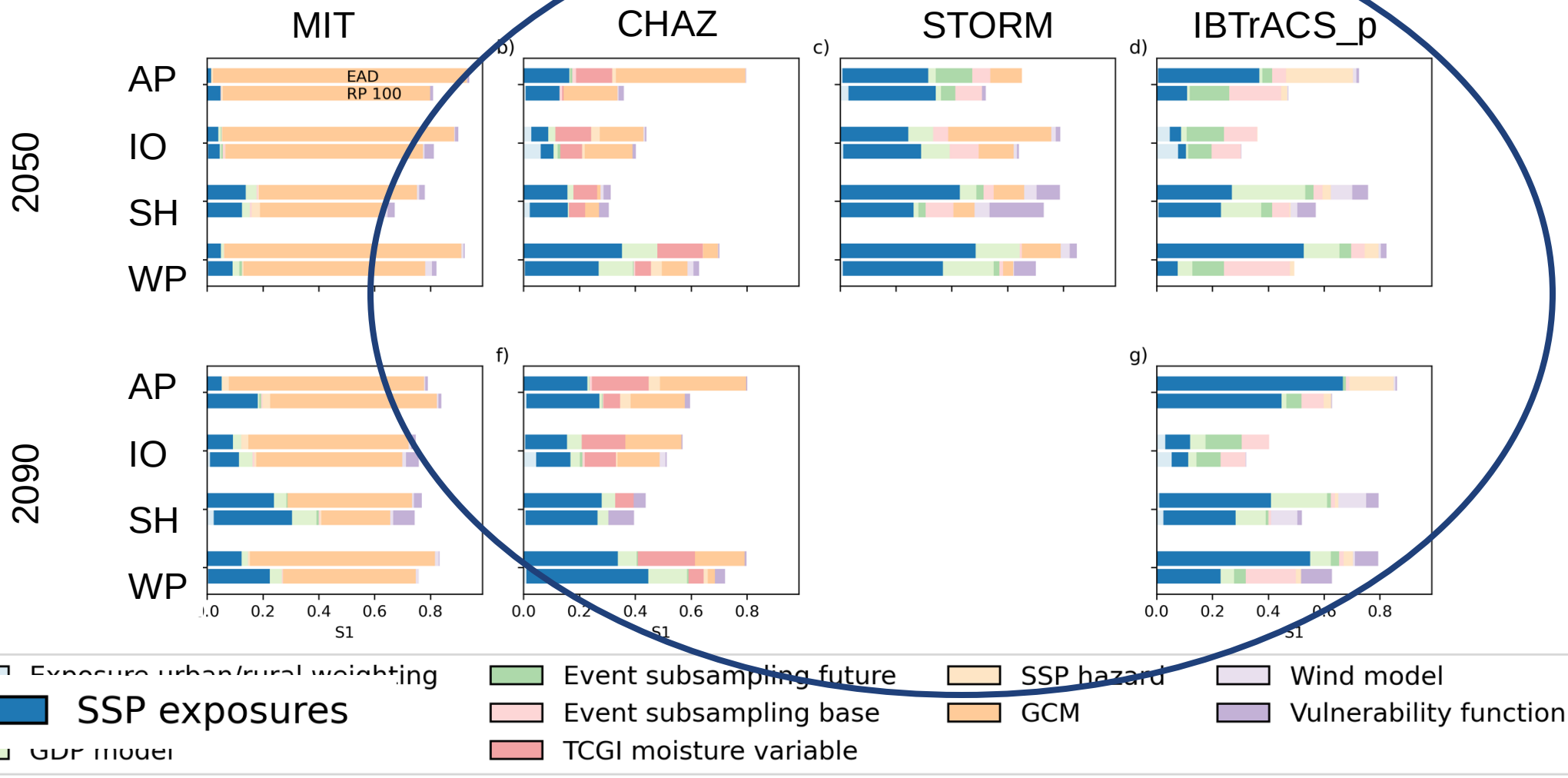


- Exposure urban/rural weighting
- SSP exposures
- GDP model
- Event subsampling future
- Event subsampling base
- TCGI moisture variable
- SSP hazard
- GCM
- Wind model
- Vulnerability function midpoint

* Meiler et al. (2024), *under review*

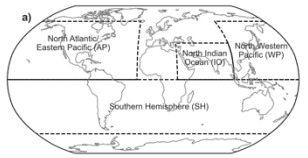
Results: Sensitivity indices

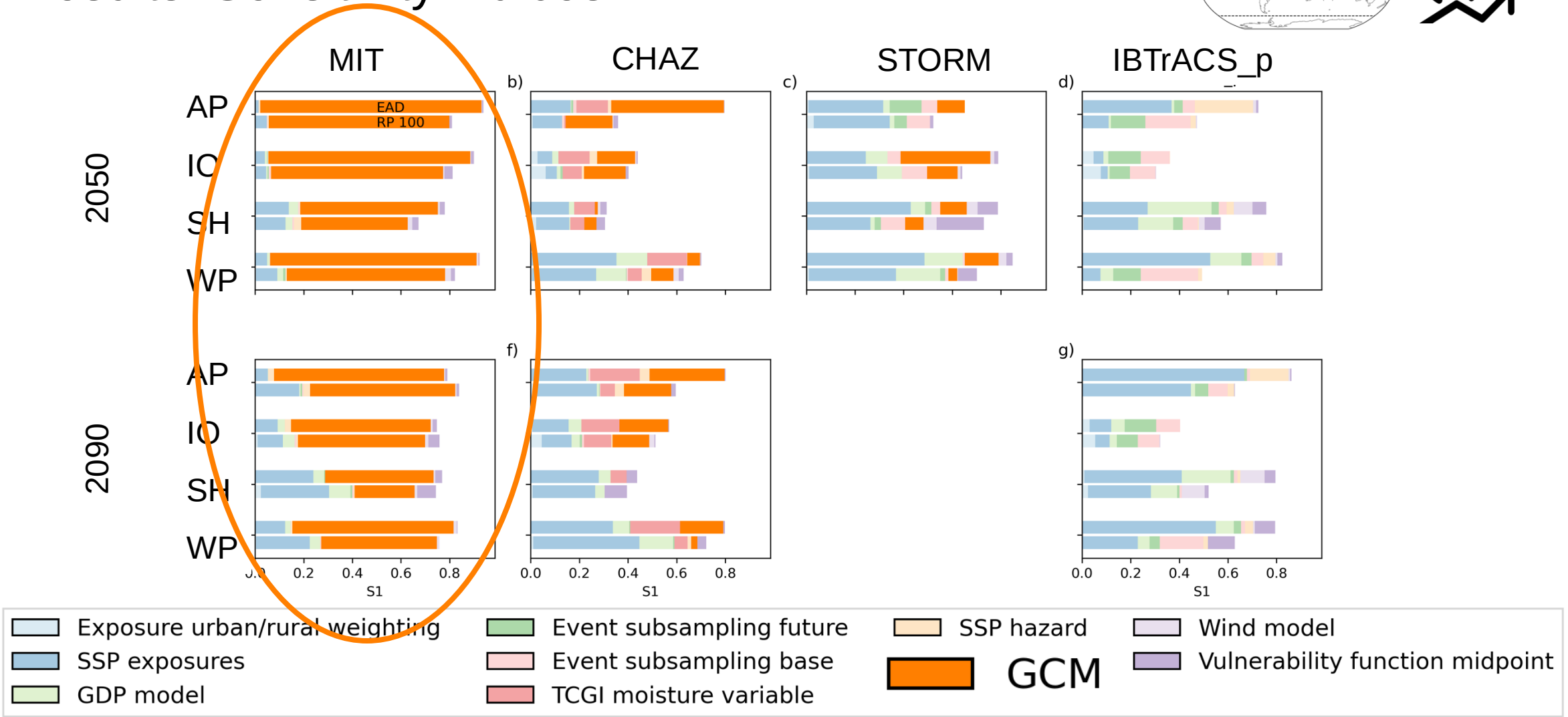




* Meiler et al. (2024), *in revision*

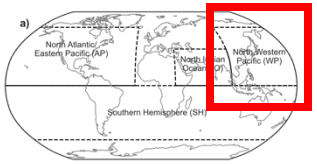
Results: Sensitivity indices

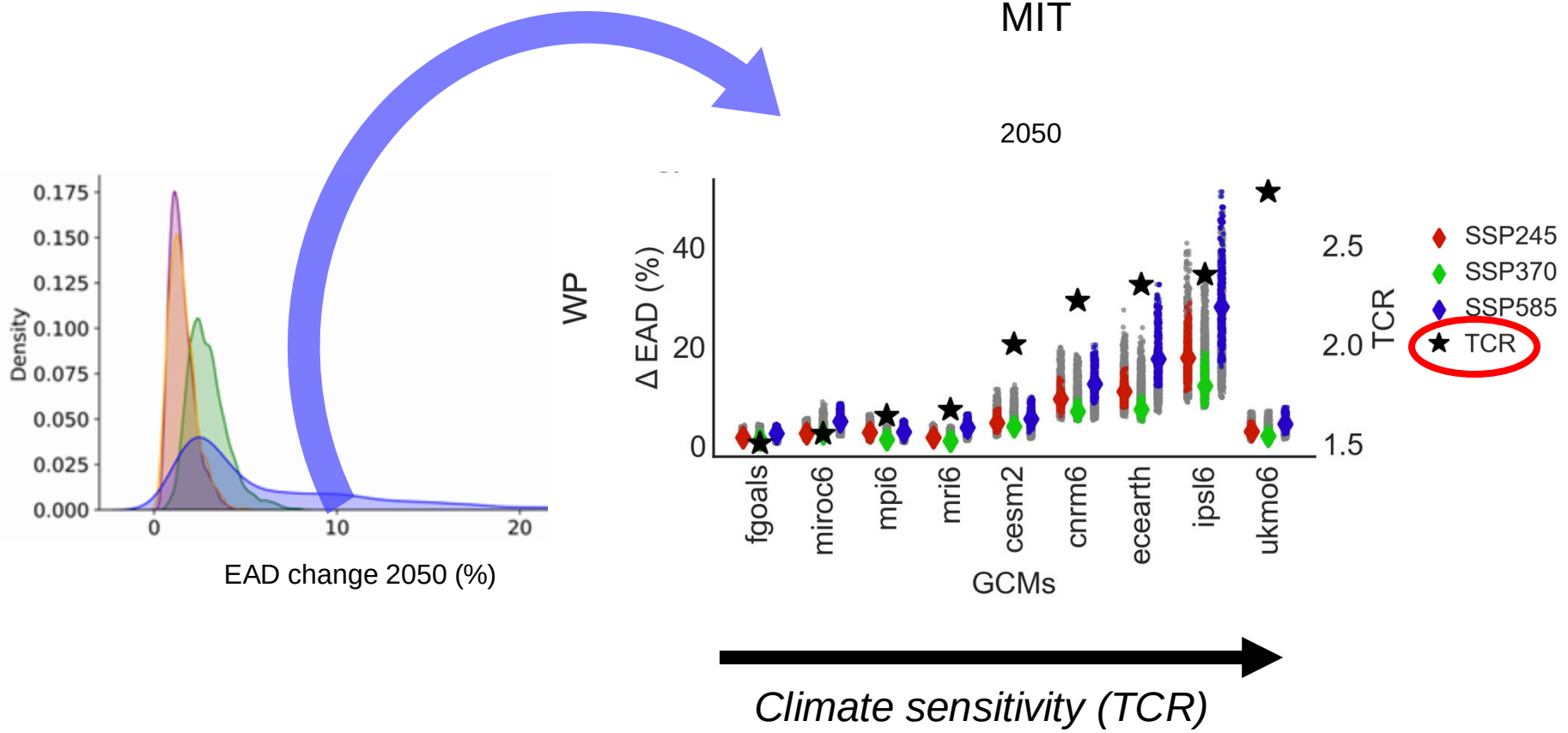




* Meiler et al. (2024), *in revision*

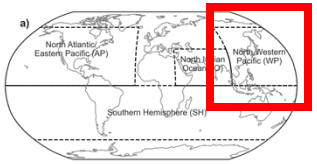
Relationship to climate sensitivity in GCMs





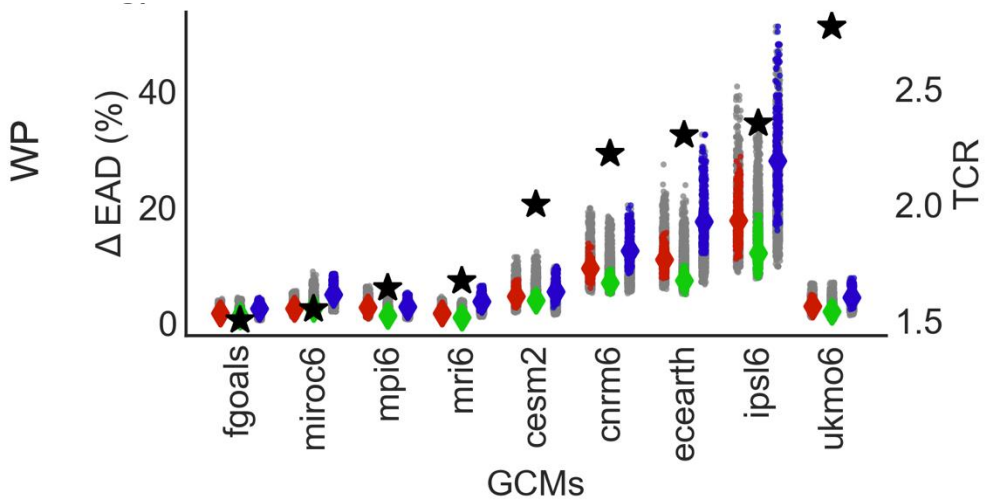
[10] Meiler et al. (2023a), *Comms Earth & Env*

Relationship to climate sensitivity in GCMs



MIT

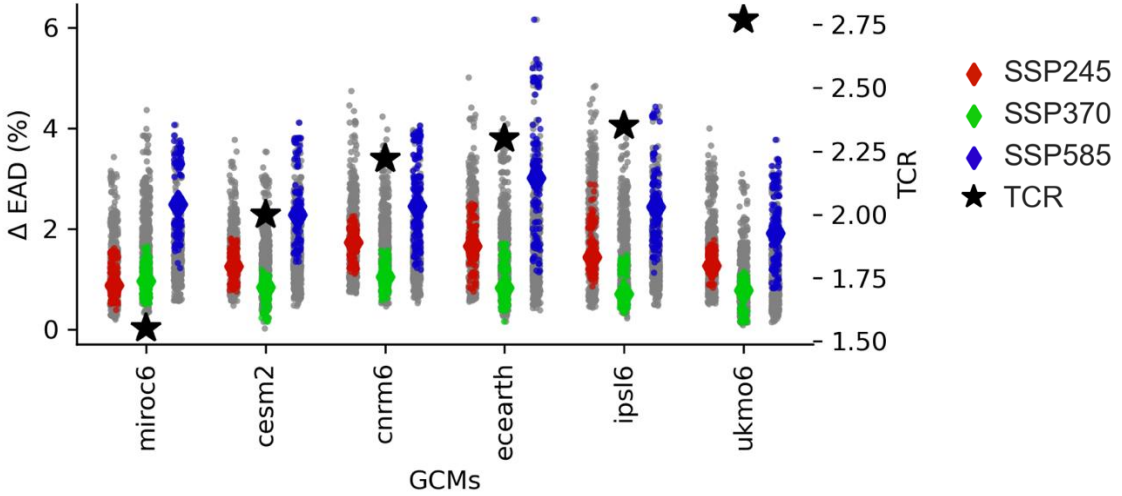
2050



Climate sensitivity (TCR)

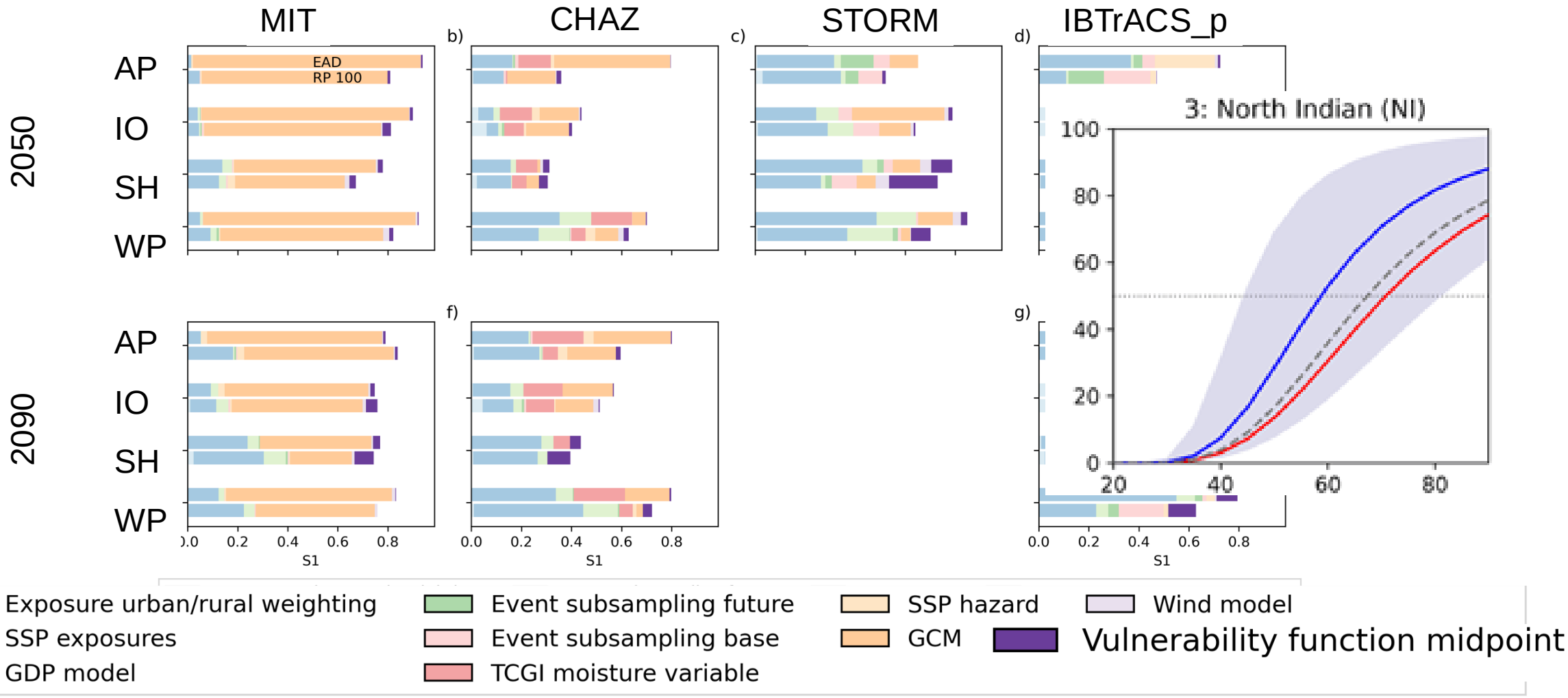
CHAZ

2050



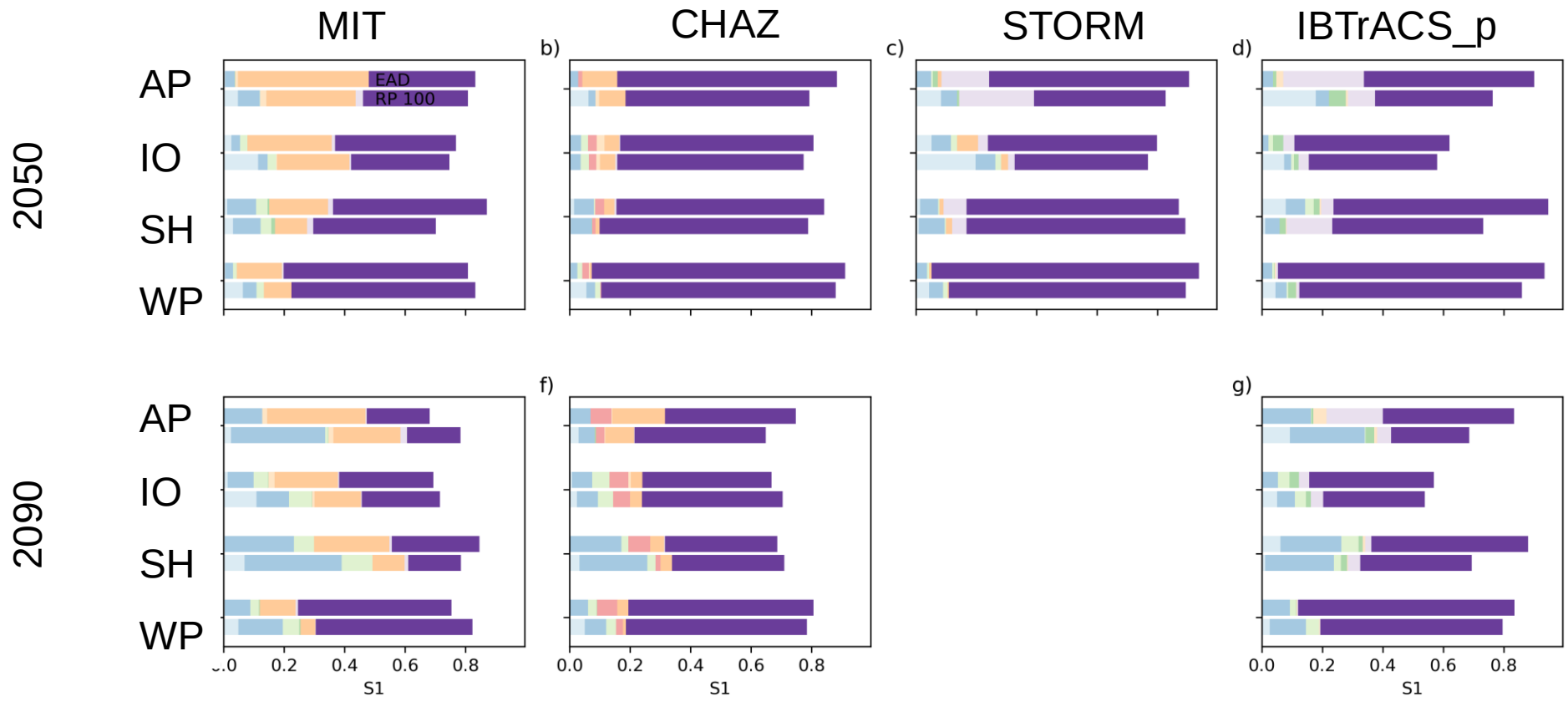
[10] Meiler et al. (2023a), *Comms Earth & Env*

Relative risk change vs. absolute risk



* Meiler et al. (2024), *in revision*

Relative risk change vs. absolute risk



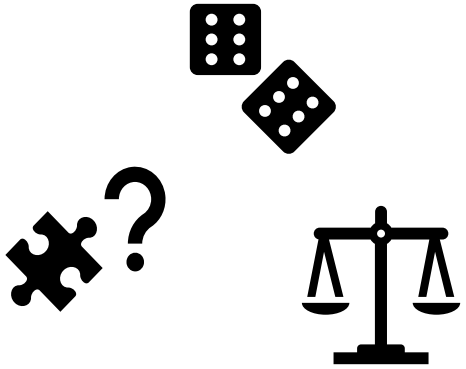
Exposure urban/rural weighting
SSP exposures
GDP model
Event subsampling future
Event subsampling base
TCGI moisture variable
SSP hazard
GCM
Wind model
Vulnerability function midpoint

* Meiler et al. (2024), *in revision*

Discussion

Back to reality – types of uncertainty

quantitative analysis × classes of uncertainty → implications



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

* Meiler et al. (2024), *in revision*

Conclusion

Unraveling unknowns in tropical cyclone risk assessment

I. Present-day tropical cyclone model intercomparison on the impact level
   → Guidance in hazard set choice

II. Systematic uncertainty & sensitivity analysis for future tropical cyclone risk
   → Enhanced transparency and depth of risk assessments.

III. Synthesis of uncertainty and sensitivity analyses across multiple hazard models
   → Structured and comprehensive perspective on implications and reducibility of uncertainties.

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Thank you & Questions?

simona.meiler@usys.ethz.ch