Fast climate risk emulation for IAM scenarios

Edward Byers, Michaela Werning, Keywan Riahi, & Volker Krey

Climate | Resilience | Europe
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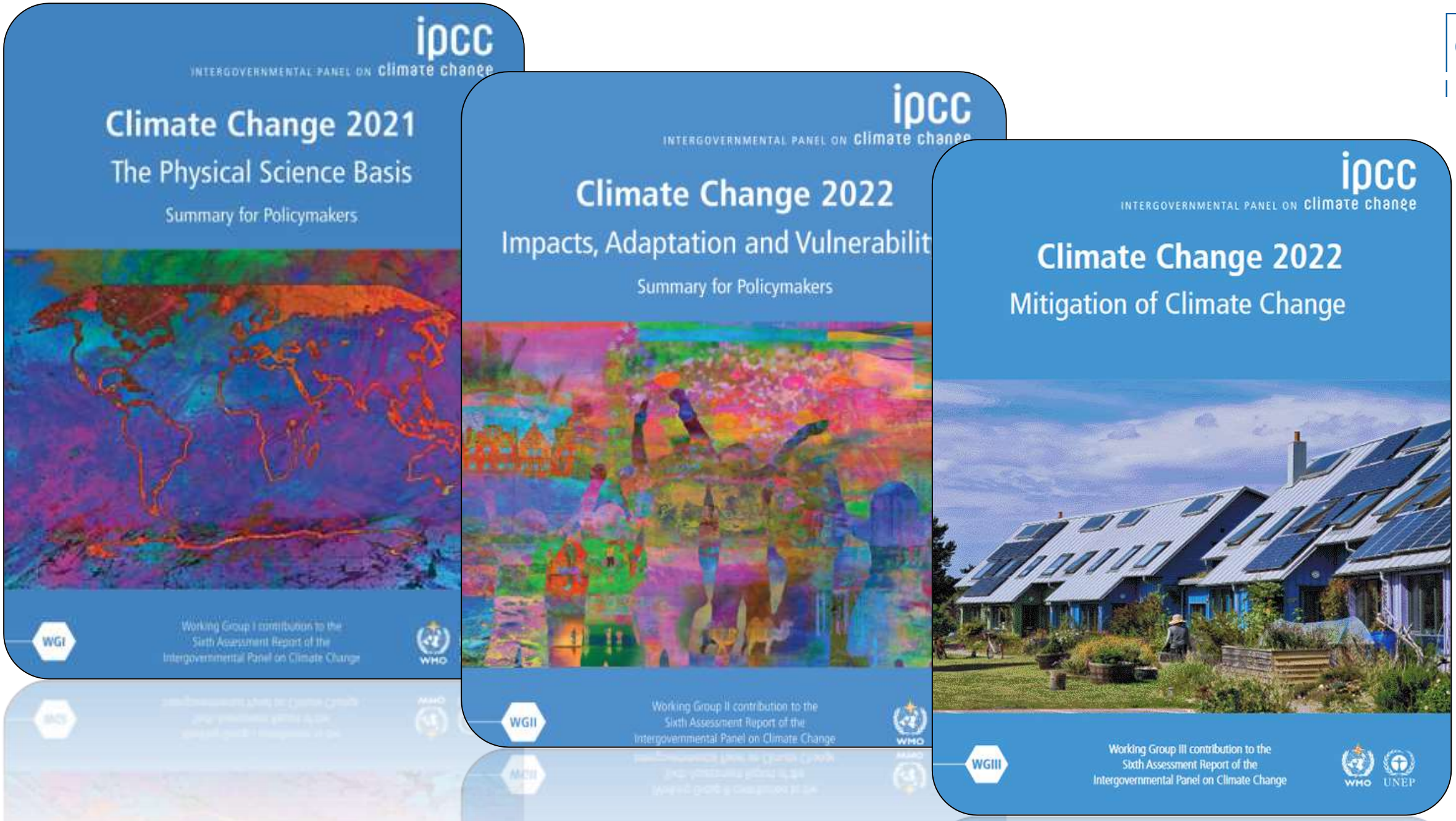
RIME
RAPID IMPACT MODEL EMULATOR

IAMC
Integrated Assessment Modeling Consortium
Founded 2007

IAMC Annual Meeting 2023
Venice

14th November 2023


ipcc
INTERGOVERNMENTAL PANEL ON climate change
Climate Change 2021
The Physical Science Basis
Summary for Policymakers
WGI
Working Group I contribution to the
Sixth Assessment Report of the
Intergovernmental Panel on Climate Change
WMO
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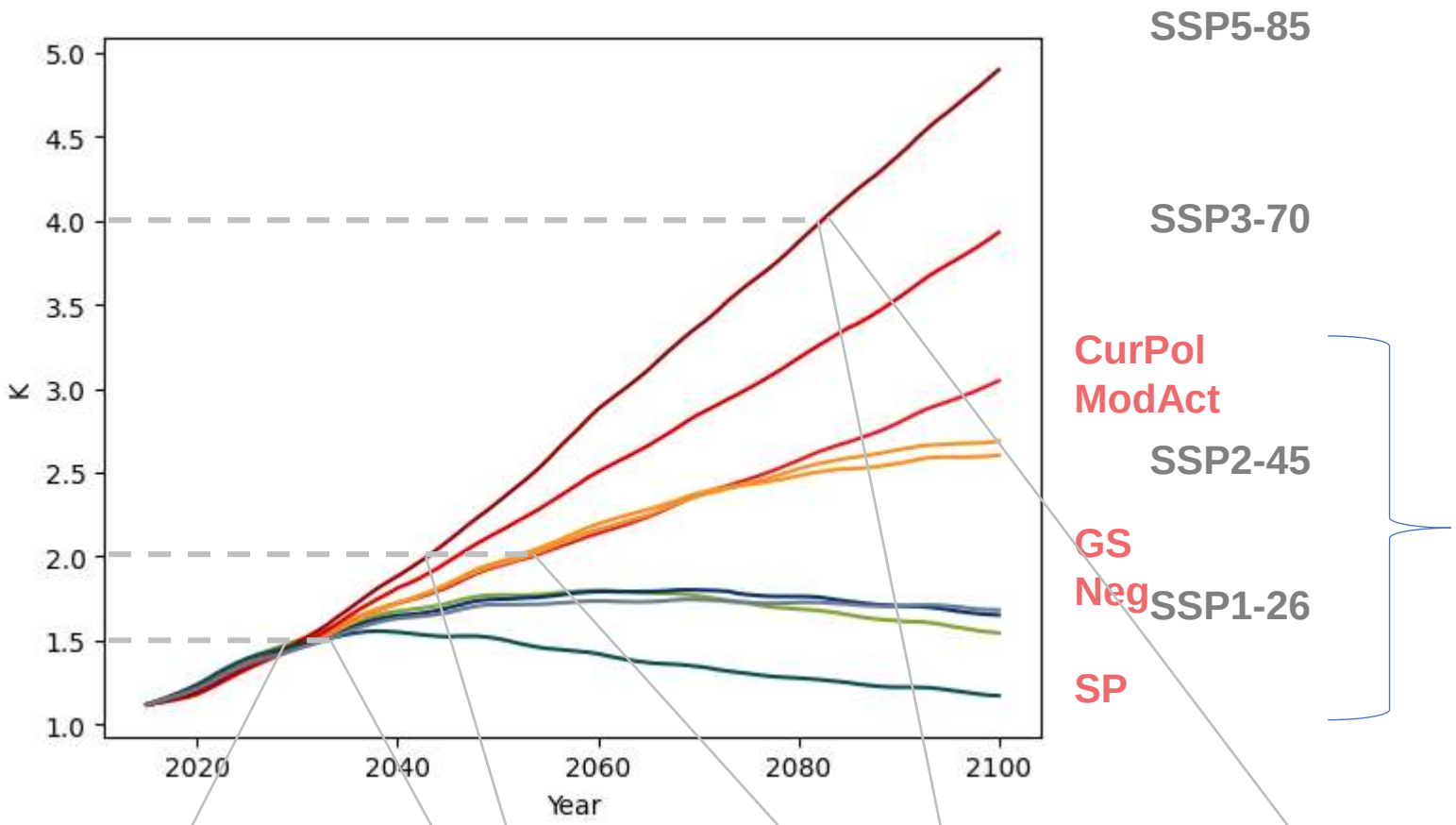
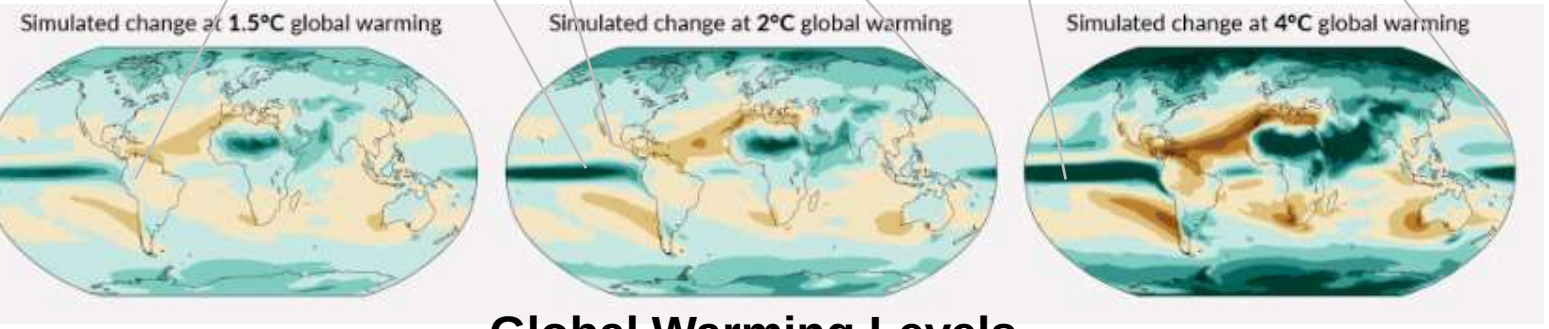
INTERGOVERNMENTAL PANEL ON climate change
Climate Change 2022
Mitigation of Climate Change
WGIII
Working Group III contribution to the
Sixth Assessment Report of the
Intergovernmental Panel on Climate Change
WMO
UNEP

Climate impacts driven by RCPs and GWLs





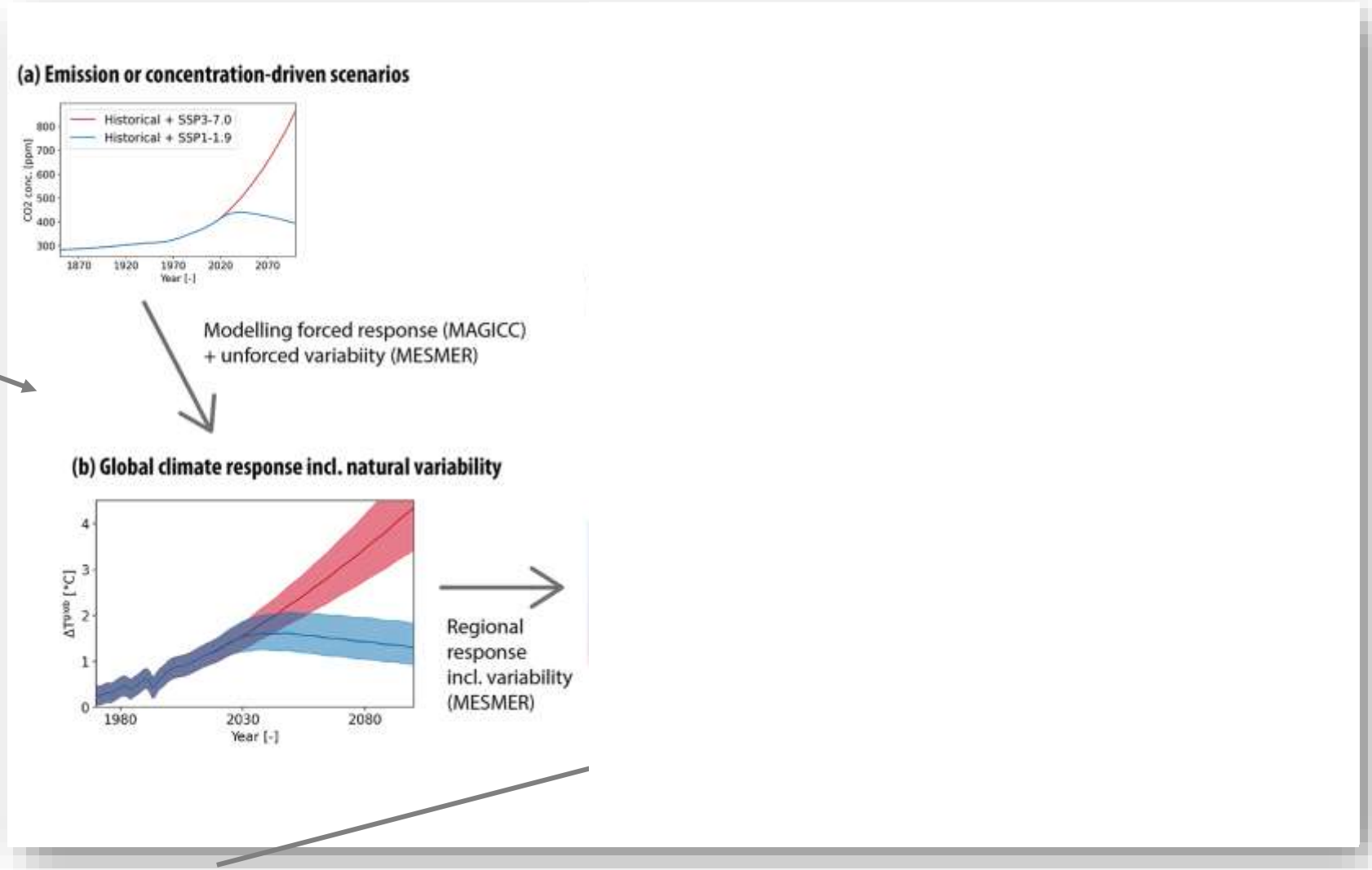
Global Warming Levels

How can we compare climate impacts without running GCMs?

Emulators!

Simple Climate Models
(MAGICC, FAiR, OSCAR, HECTOR,…)

- Primarily aimed at emulating atmosphere, CO_2 ppm, radiative forcing and global temperature
- Limited spatial resolution, probabilistic, annual timeseries



Beusch et al. 2022. GMD

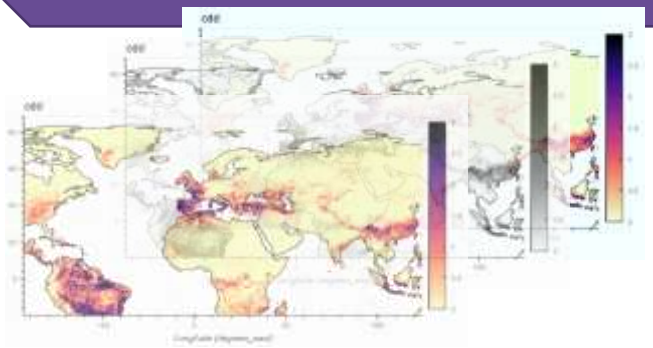
Earth System emulators (MESMER, STITCHES, fIdgen…)

- Gridded climate variables, at annual or monthly resolution as timeseries with natural variability
- Temperature, precipitation, soil moisture, fire weather,…

RIME
RAPID IMPACT MODEL EMULATOR

Aim: Rapid emulation of long-term climate impacts & risk indicators

More impacts
Temp & Precip. extremes, drought, CDD, hydrology, crop yield potentials, fire weather, …



SSP and model uncertainties
- Climate-Impact model quantiles
- SSPs for population exposure & vulnerability

IAMC Integrated Assessment Modeling Consortium Founded 2007 ⟷ ISIMIP Inter-Sectoral Impact Model Intercomparison Project

Community friendly
Designed for ISIMIP & IAM inter-operability and inter-comparison

Integrated assessment and workflow

IAM emissions → Climate emulation → Impact emulation → Database

Use cases

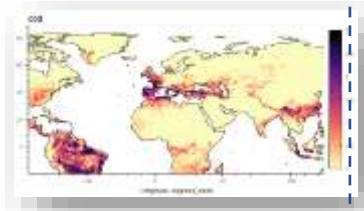
Mode

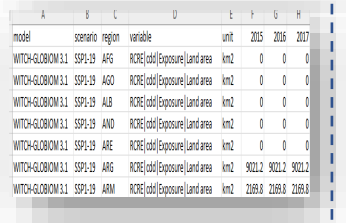
Post-process

1. I want estimates of climate impacts for emissions scenarios

Emissions or GMT scenario + **Climate impacts by GWL** → **IAM scenario (no CC)** +

Impacts maps



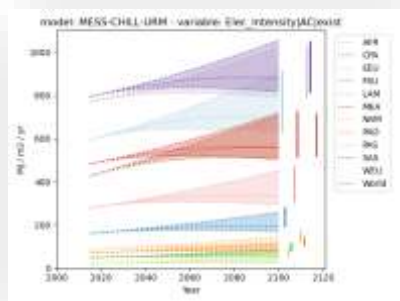


Impacts tables

Input

2. I want to <u>input</u> climate impacts into an IAM that isn't an RCP trajectory

IAM scenario inputs + **Climate impacts by GWL** → **Trajectory of climate impacts (input to IAM)**



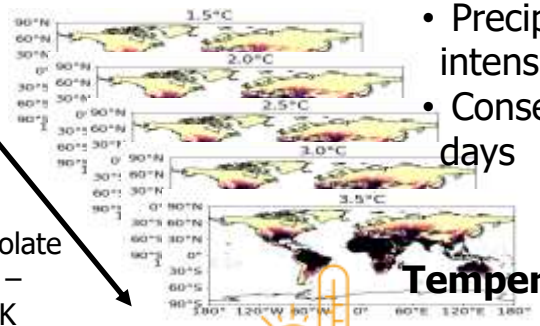
2. Workflow

IAM global CO_2 emissions

Database of impacts and exposures by GWL (GMT, year, SSP, region)

(Werning et al. 2023)

Temperature trajectory (e.g. AR6 SCM)



Interpolate ΔGMT – 0.01° K

```
<xarray.Dataset>
Dimensions:          (gmt: 251, year: 91, ssp: 3,
                      region: 226)
Coordinates:
  * gmt              (gmt) float64 1.2 1.206 ... 3.5
  * year             (year) int64 2010 2011 ... 2100
  * ssp              (ssp) object 'SSP1' 'SSP2' 'SSP3'
  * region           (region) object 'AFG' ... 'world'
Data variables: (12/189)
    iavar|Exposure|Land area
    iavar|Exposure|Land area|%
    iavar|Exposure|Land area|High
    iavar|Exposure|Land area|High|%
    iavar|Exposure|Land area|Low
    iavar|Exposure|Land area|Low|%
    ...
    sdii|Hazard|Difference
    sdii|Hazard|Difference|Land area weighted
    sdii|Hazard|Difference|Population weighted
    sdii|Hazard|Risk score
    sdii|Hazard|Risk score|Land area weighted
    sdii|Hazard|Risk score|Population weighted
```

Precipitation

- Heavy precipitation days
- Wet & very wet days
- Precipitation intensity index
- Consecutive dry days

Hydrology (runoff & discharge)

- Drought intensity
- Seasonality
- Interannual variability
- Water stress

Temperature

- Heat wave intensity
- Tropical nights

Energy demands

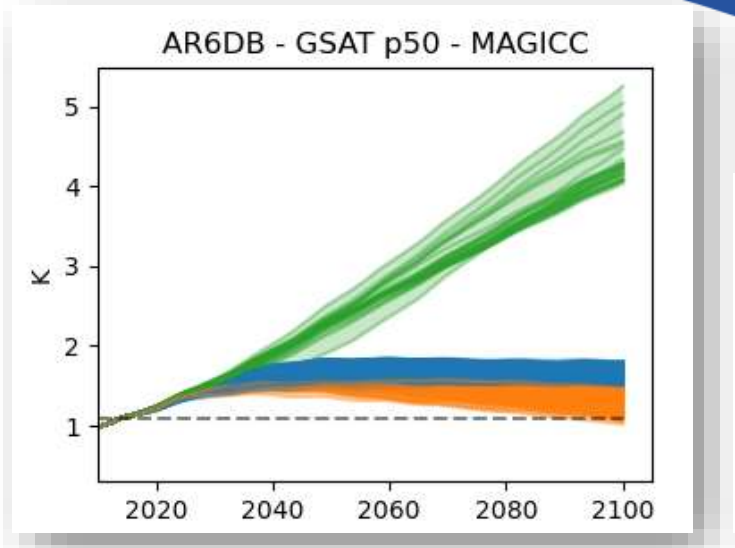
- Cooling degree days
- Energy intensity*

Perform **multi-index lookup** of trajectory

Fire weather index*

** In development*

↓ 3.5 °C



Million people exposed to impact X **→ 2100**

gmt	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1.20	82.0	82.7	83.4	84.0	84.7	85.4	85.9	86.5	87.0	87.5	88.0	88.6	89.1	89.6	90.1	90.6
1.21	83.3	84.0	84.7	85.4	86.1	86.8	87.3	87.9	88.4	88.9	89.5	90.0	90.5	91.0	91.6	92.1
1.22	84.7	85.4	86.1	86.8	87.5	88.2	88.7	89.3	89.8	90.3	90.9	91.4	91.9	92.5	93.0	93.6
1.23	86.0	86.7	87.4	88.1	88.9	89.6	90.1	90.7	91.2	91.7	92.3	92.8	93.4	93.9	94.5	95.0
1.24	87.3	88.1	88.8	89.5	90.2	91.0	91.5	92.1	92.6	93.2	93.7	94.3	94.8	95.4	95.9	96.5
1.25	88.7	89.4	90.1	90.9	91.6	92.3	92.9	93.5	94.0	94.6	95.1	95.7	96.2	96.8	97.4	97.9
1.26	90.0	90.7	91.5	92.2	93.0	93.7	94.3	94.9	95.4	96.0	96.6	97.1	97.7	98.2	98.8	99.4
1.27	91.3	92.1	92.8	93.6	94.4	95.1	95.7	96.3	96.8	97.4	98.0	98.5	99.1	99.7	100.3	100.8
1.28	92.7	93.4	94.2	95.0	95.7	96.5	97.1	97.7	98.2	98.8	99.4	100.0	100.6	101.1	101.7	102.3
1.29	94.0	94.8	95.6	96.3	97.1	97.9	98.5	99.1	99.6	100.2	100.8	101.4	102.0	102.6	103.2	103.7
1.30	95.3	96.1	96.9	97.7	98.5	99.3	99.9	100.5	101.1	101.6	102.2	102.8	103.4	104.0	104.6	105.2
1.31	96.7	97.5	98.3	99.1	99.9	100.7	101.3	101.9	102.5	103.1	103.7	104.3	104.9	105.5	106.1	106.7
1.32	98.0	98.8	99.6	100.4	101.2	102.0	102.6	103.3	103.9	104.5	105.1	105.7	106.3	106.9	107.5	108.1
1.33	99.3	100.2	101.0	101.8	102.6	103.4	104.0	104.7	105.3	105.9	106.5	107.1	107.7	108.3	109.0	109.6
1.34	100.7	101.5	102.3	103.2	104.0	104.8	105.4	106.1	106.7	107.3	107.9	108.5	109.2	109.8	110.4	111.0
1.35	102.0	102.9	103.7	104.5	105.4	106.2	106.8	107.5	108.1	108.7	109.3	110.0	110.6	111.2	111.9	112.5
1.36	103.4	104.2	105.0	105.9	106.7	107.6	108.2	108.9	109.5	110.1	110.8	111.4	112.0	112.7	113.3	113.9

Community consistent output formats

IAMC table format

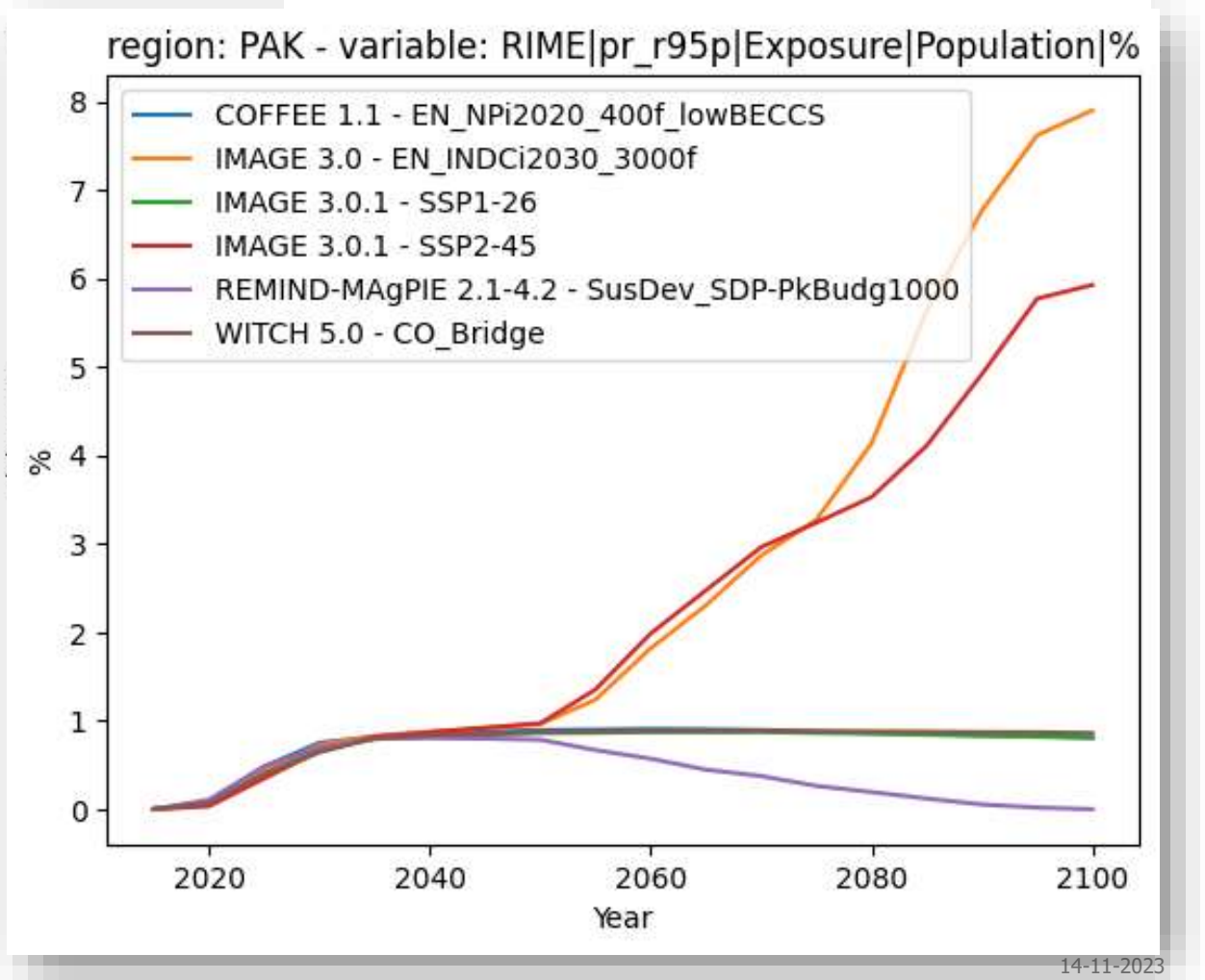
`process_tabledata(df,ds,…)`

	A	B	C	D	E	F	G	H
	model	scenario	region	variable	unit	2015	2016	2017
	WITCH-GLOBIOM 3.1	SSP1-19	AFG	RCRE|cdd|Exposure|Land area	km2	0	0	0
	WITCH-GLOBIOM 3.1	SSP1-19	AGO	RCRE|cdd|Exposure|Land area	km2	0	0	0
	WITCH-GLOBIOM 3.1	SSP1-19	ALB	RCRE|cdd|Exposure|Land area	km2	0	0	0
	WITCH-GLOBIOM 3.1	SSP1-19	AND	RCRE|cdd|Exposure|Land area	km2	0	0	0
	WITCH-GLOBIOM 3.1	SSP1-19	ARE	RCRE|cdd|Exposure|Land area	km2	0	0	0
	WITCH-GLOBIOM 3.1	SSP1-19	ARG	RCRE|cdd|Exposure|Land area	km2	9021.2	9021.2	9021.2
	WITCH-GLOBIOM 3.1	SSP1-19	ARM	RCRE|cdd|Exposure|Land area	km2	2169.8	2169.8	2169.8

Aggregated by region (country, continent, IAM region e.g. R10)

Multiple indicators, scenarios and regions in simple tabular format (IAMC.csv)

Extreme precipitation days - Pakistan



Byers, Werning, et al. - Fast climate risk emulation for IAM scenarios.

Community consistent output formats

Spatial gridded netCDF maps

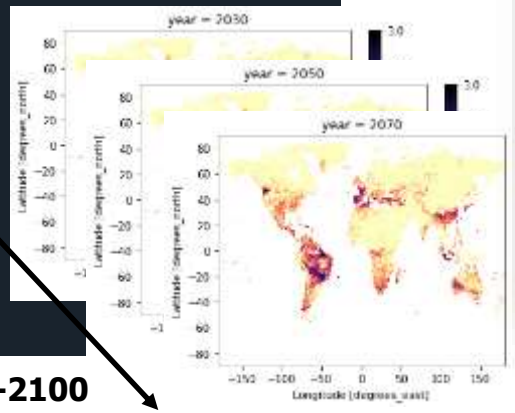
`maps_transform_gmt_wrapper(df,ds,…)`

Multiple IAM scenarios, one impact indicator

```
<xarray.Dataset>
Dimensions:                (lat: 360, lon: 720, year: 86)
Coordinates:
  * lon                    (lon) float64 -179.8 -179.2 -178.8 ... 179.2 179.8
  * lat                    (lat) float64 89.75 89.25 88.75 ... -89.25 -89.75
  * year                   (year) int32 2015 2016 2017 2018 ... 2098 2099 2100
Data variables:
    AIM_CGE_2.0_SSP1-26    (lat, lon, year) float64 ...
    GCAM_5.3_SSP_SSP5      (lat, lon, year) float64 ...
```

One IAM scenario, multiple impact indicators

```
<xarray.Dataset>
Dimensions:      (lat: 360, lon: 720, year: 86)
Coordinates:
  * lon          (lon) float64 -179.8 -179.2 -178.8 -178.2 ... 178.8 179.2 179.8
  * lat          (lat) float64 89.75 89.25 88.75 88.25 ... -88.75 -89.25 -89.75
  * year         (year) int32 2015 2016 2017 2018 2019 ... 2097 2098 2099 2100
Data variables: (12/18)
    cdd          (lat, lon, year) float64 ...
    dri          (lat, lon, year) float64 ...
    dri_qtot     (lat, lon, year) float64 ...
    iavar        (lat, lon, year) float64 ...
    iavar_qtot   (lat, lon, year) float64 ...
    pr_r10       (lat, lon, year) float64 ...
    ...           ...
    sdd_c        (lat, lon, year) float64 ...
    sdd_c_24p0   (lat, lon, year) float64 ...
    sdd_c_20p0   (lat, lon, year) float64 ...
    sdd_c_18p3   (lat, lon, year) float64 ...
    tr20         (lat, lon, year) float64 ...
    wsi          (lat, lon, year) float64 ...
```

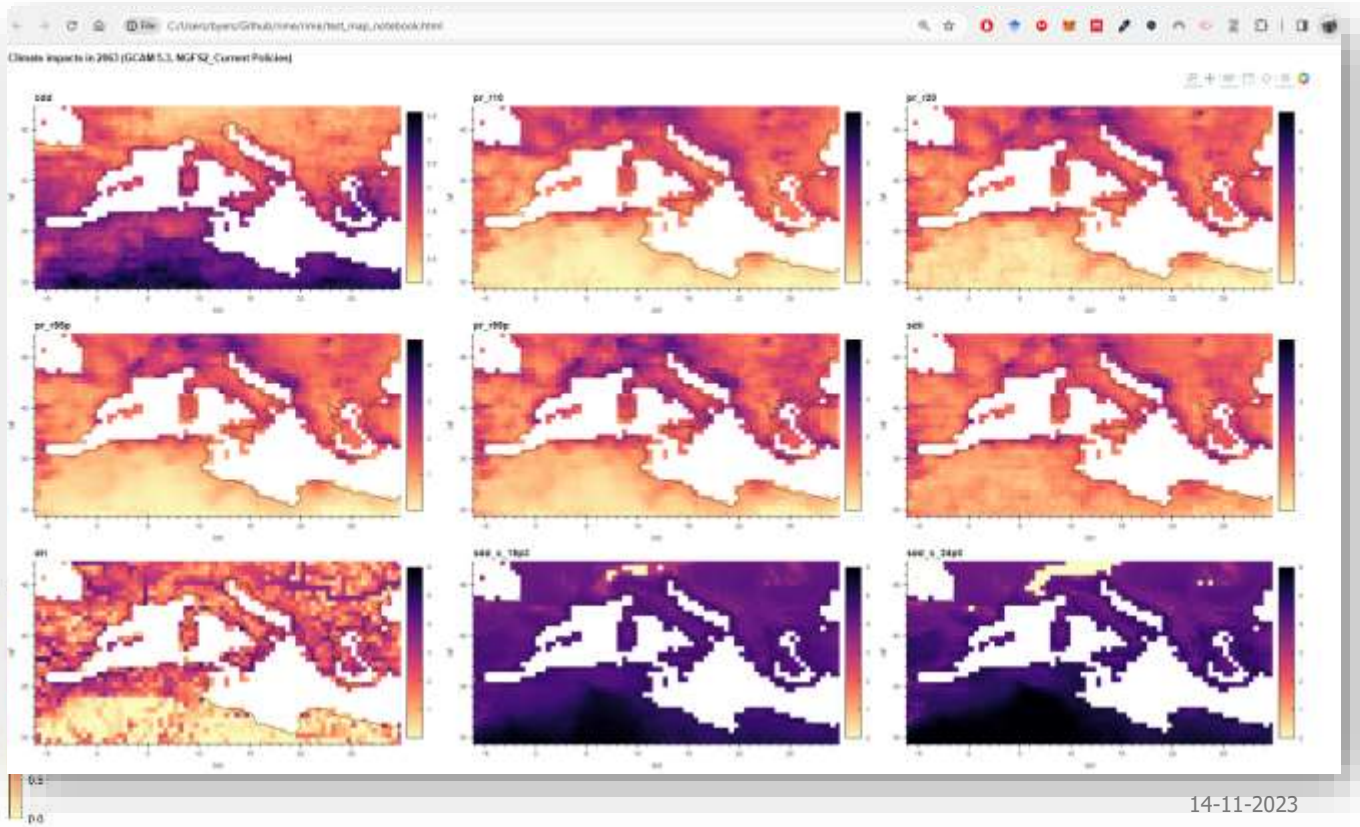


2015 -2100

Interactive html dashboards

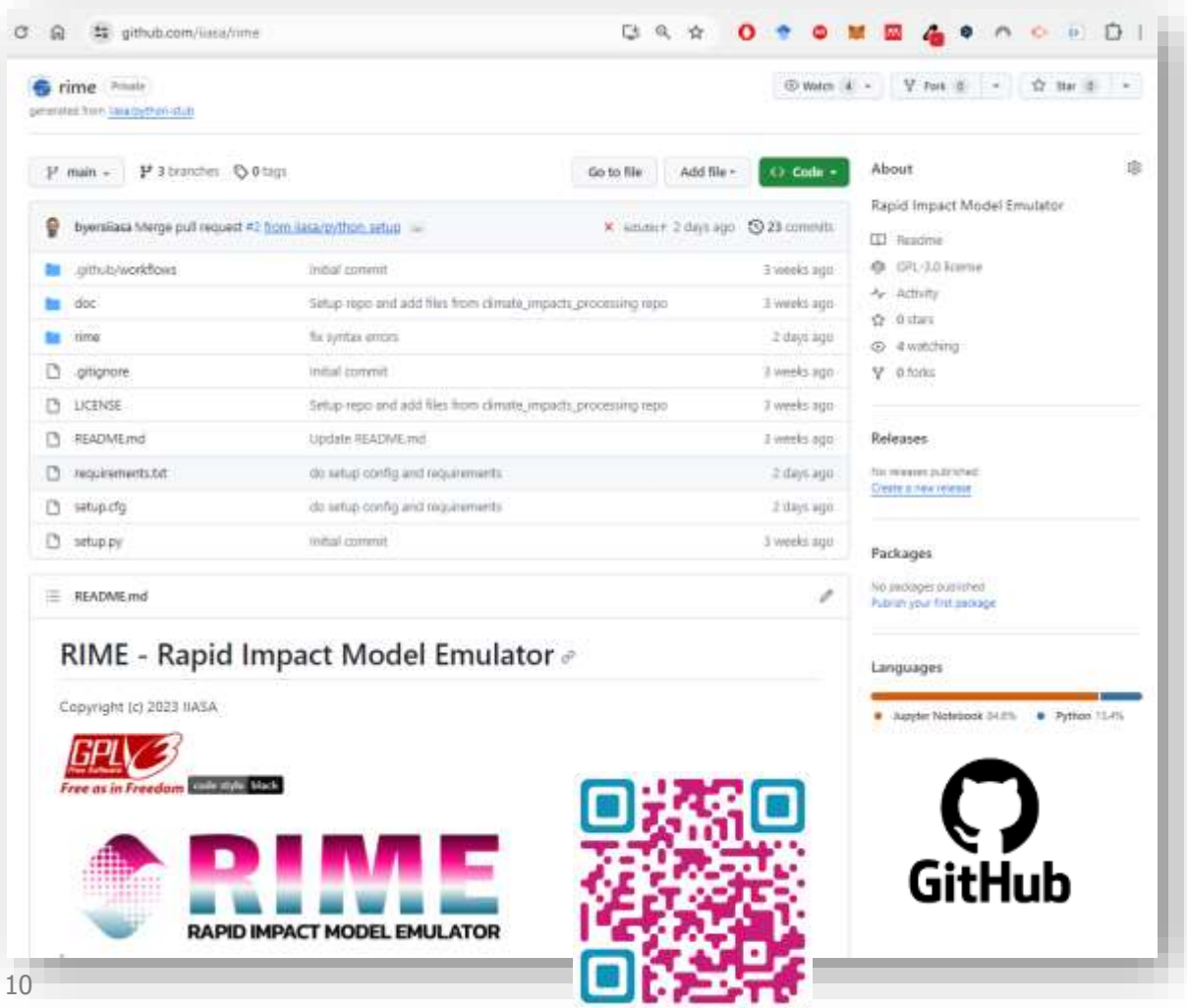
Indicator or scenario comparison in year X

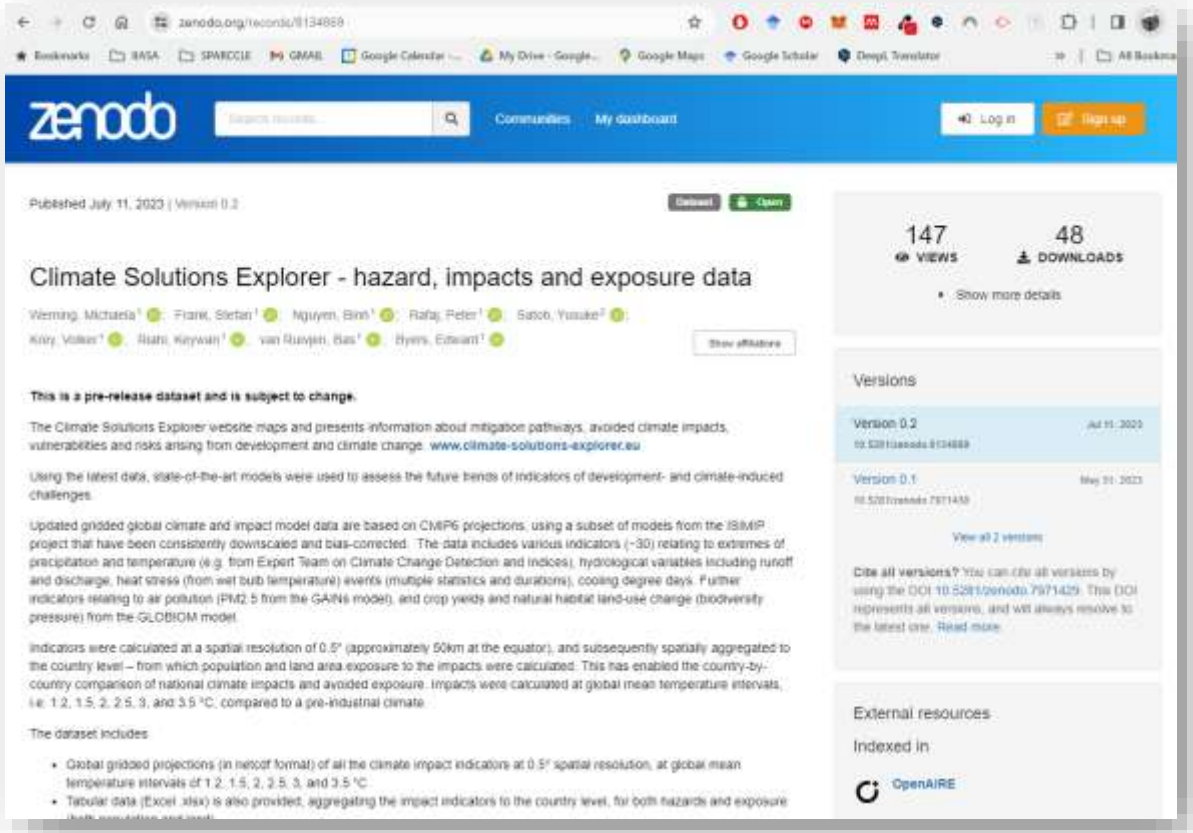
`plot_maps_dashboard(ds)`



Software and data – in the wild!

www.github.com/iiasa/rime **Pre-release** https://zenodo.org/records/8134869





www.climate-solutions-explorer.eu

Conclusions and next steps

1. Rapid impacts emulation

Software

- Scripts for interpolation and re-indexing
  - Input: GMT or CO2 trajectory by year (.csv)
  - Output: Impact indicators by year (.csv, netCDF)
- Python: Xarray + Dask parallelized == *Rapid!*

Data

- Database of gridded and country-level impacts and exposure (Werning et al. 2023)
- Extend to more indicators + vulnerability

Community assessment

- Post-processing of IAM scenarios for scenarios assessment
- Support IPCC WG1-WG2-WG3 integration

2. Impacts integration into IAMs

- Test more impacts, e.g., hydrology, water supply, power supply, biomass potential (CDR)
- Support climate impacts assessment of unknown emissions scenarios

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Socioeconomic Pathways, Adaptation and Resilience to a Changing Climate in Europe

International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

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IIASA

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https://github.com/iiasa/rime

RIME
RAPID IMPACT MODEL EMULATOR

Implementation

python
xarray
pyam
pandas
dask
GitHub

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Acknowledged support

ENGAGE
FEASIBILITY OF CLIMATE PATHWAYS

IAMC
Integrated Assessment Modeling Consortium
Founded 2007

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project