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Closing loops - the rapid emulation of climate risks and integration into IAMs

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SPARCCLE
IAMC
Integrated Assessment Modeling Consortium
Founded 2007
RITE
Research Institute of Innovative Technology for the Earth
SYSTEMS ANALYSIS GROUP
ISIMIP
Inter-Sectoral Impact Model Intercomparison Project
PROCLIAS

Cross-sectoral ISIMIP and PROCLIAS Workshop
Sector meeting: Energy

5th June 2023

Climate impacts emulation and integration with IAM scenarios

1. Demonstrate integration into IAM for building cooling demands:

- Emulate climate impacts on energy intensity for cooling using ISIMIP forcing data
- Use as inputs into IAM scenarios

2. Climate impacts emulation from IAM scenarios :

- Expanding number of emulators (e.g., FaIR, MAGICC, OSCAR, etc.) that from an input emissions scenario, estimate global warming (e.g.– annual timeseries, global and macro-region variables. New approaches to extend this with grid-level assessment, and more climate-related variables e.g. temperatures, precipitation (MESMER, STITCHES)
- **Here:** extend approaches for climate impacts and risk assessment – e.g., heatwaves, drought => population exposed
    - Pre-process: Climate impacts & exposure data (e.g., from ISIMIP impact models)
    - Input: Global mean temperature projection (+IAM scenario), e.g., from AR6 Scenarios database
    - Output: Maps & table data of land/population exposure to impacts

1. Climate impacts on buildings cooling demand

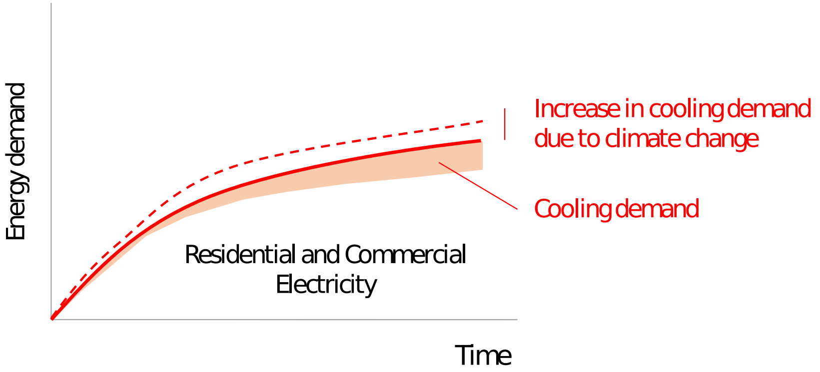
Problem: IAMs constrained to running climate impacts based on SSP-RCP trajectories

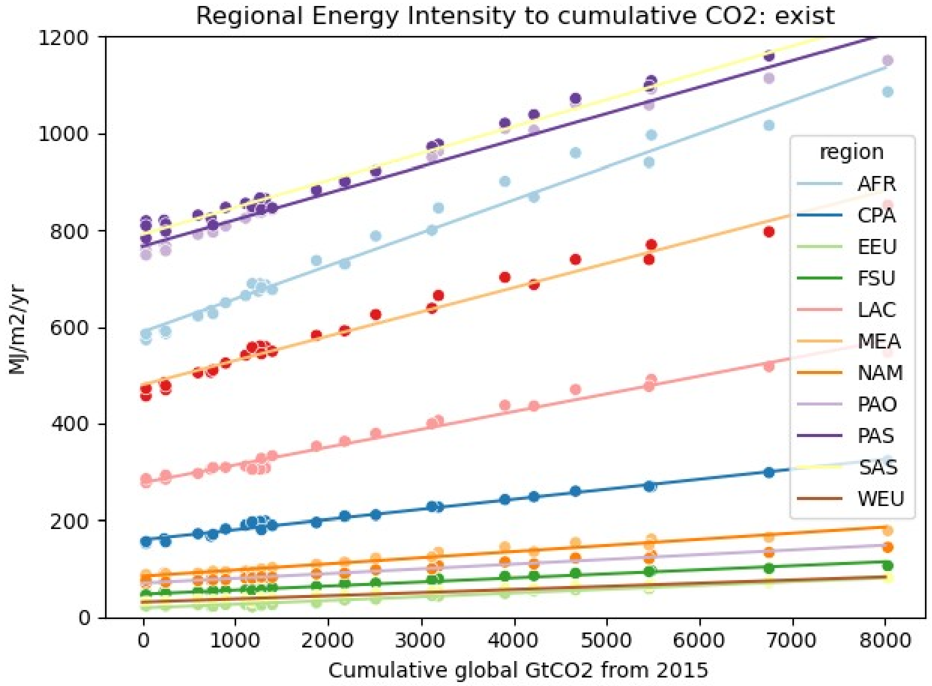
CHILLED is a gridded space cooling/heating demand model (Mastrucci et al. 2018) – inputs to MESSAGEix

Computationally expensive, constrained by SSP-RCP

Solution: Climate impact response functions that are agnostic to emissions-temp. trajectory

1. Run CHILLED with ISIMIP SSP-RCPs energy intensity (MJ/m²/yr) projections
2. Calculate cumulative CO_2
3. Develop regional response of energy intensity to cumulative CO_2



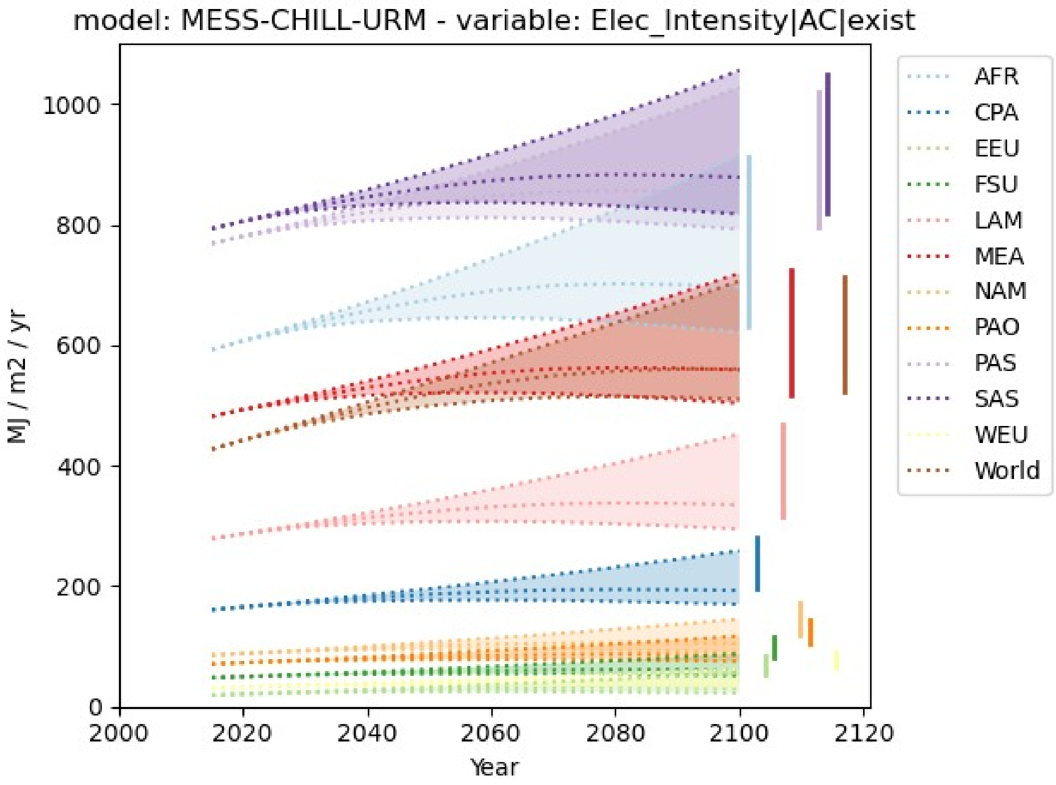


1. CHILLED emulation with regional response functions

CHILLED-STURM emulator
CC scenarios using regional response function

Input: Emissions|CO2, cumulative at each timestep, for any unseen scenario

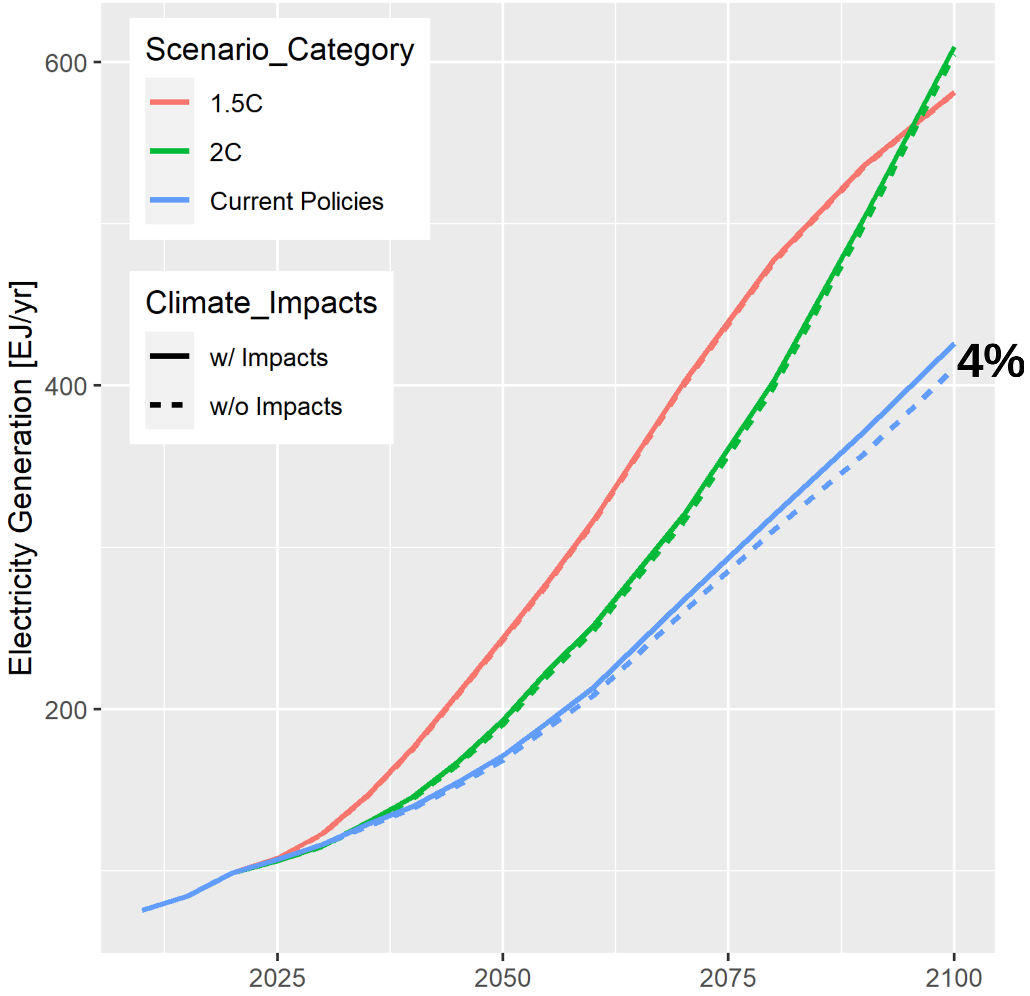
Output: Temporal projections of energy intensity, by region, building type, cooling method, SSP



3 standard runs

- 1.5°C
- 2 °C
- Current Policies (~3 °C)

1. IAM electricity gen. response to CC



15 EJ = 4167 TWh
Today: 🇺🇸

4.5 EJ = 1250 TWh
Today: 🇯🇵

2. Workflow: Map impacts

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

Input **temperature trajectory** from emission scenarios (e.g. AR6)

Precipitation

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

Hydrology

- Drought intensity
- Seasonality
- Interannual variability
- Water stress

Temperature

- Heat wave intensity
- Tropical nights

Land

- Low intensity land cover
- Crop yields

Energy demands

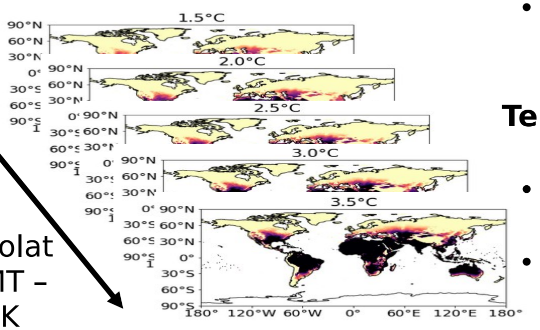
- Cooling degree days

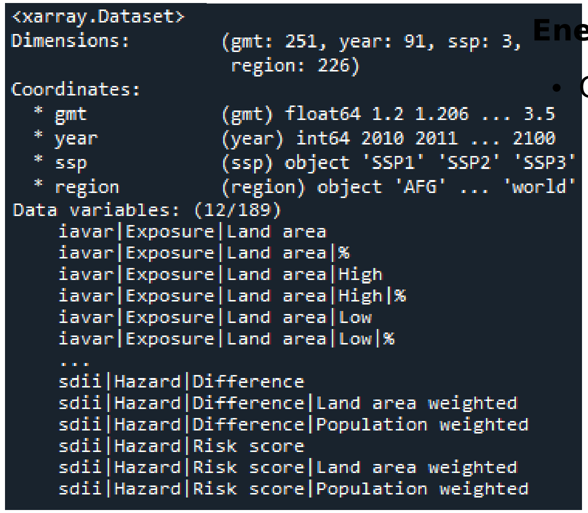
Air pollution

- Ambient PM2.5

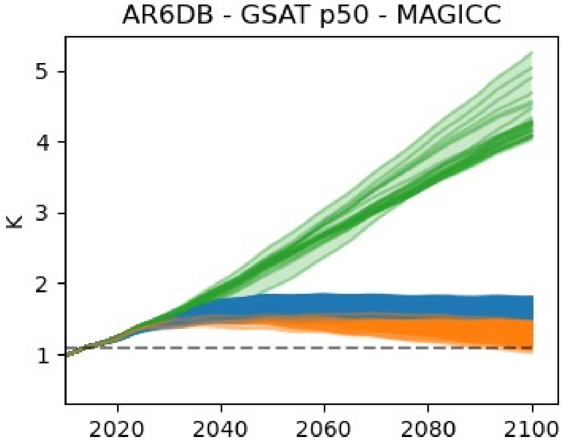
Perform **multi-index lookup** of trajectory

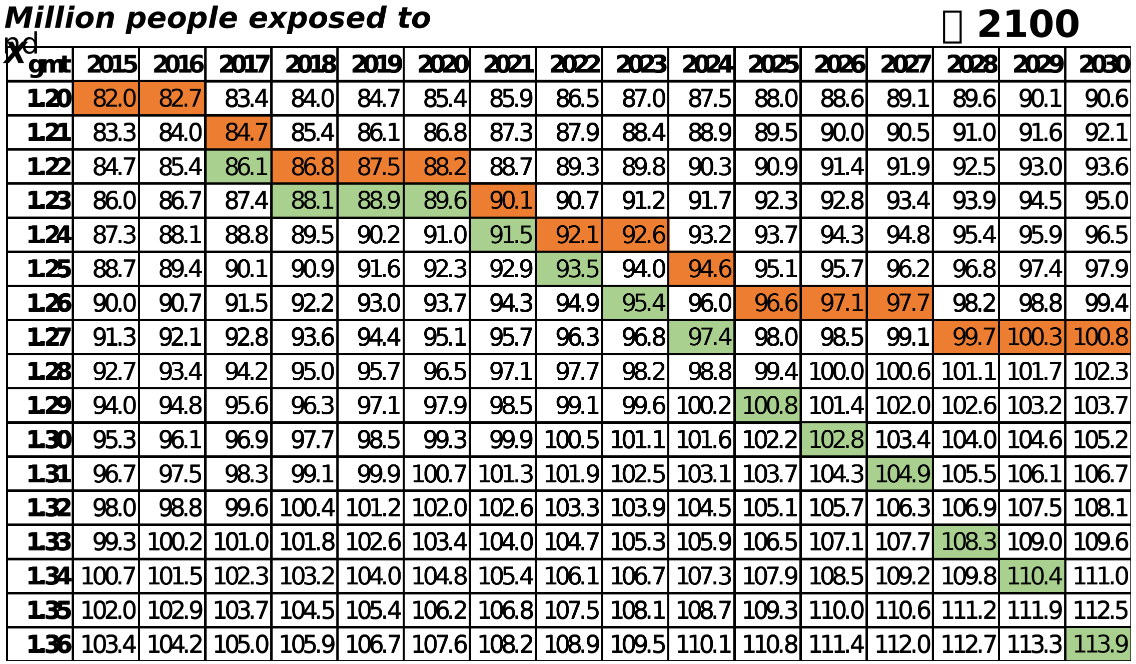
Interpolate ΔGMT – 0.01° K





```
<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
```





Million people exposed to X

□ 2100

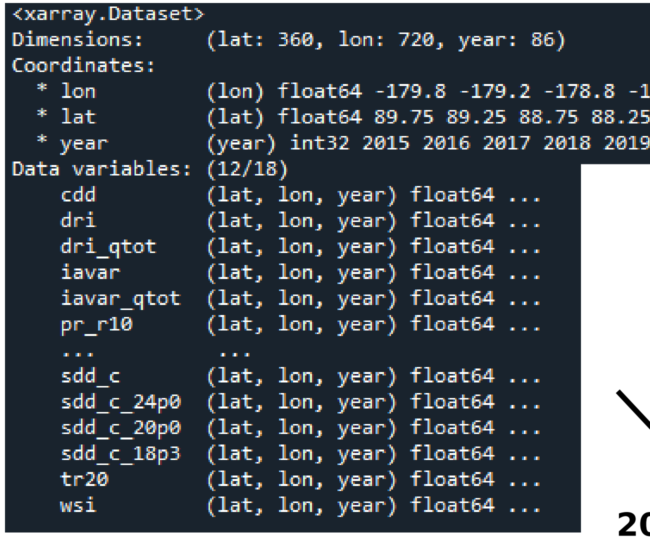
gmt	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1.20	82.0	82.7	83.4	84.0	84.7	85.4	85.9	86.5	87.0	87.5	88.0	88.6	89.1	89.6	90.1	90.6
1.21	83.3	84.0	84.7	85.4	86.1	86.8	87.3	87.9	88.4	88.9	89.5	90.0	90.5	91.0	91.6	92.1
1.22	84.7	85.4	86.1	86.8	87.5	88.2	88.7	89.3	89.8	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

↓ **3.5 °C**

2. Community consistent output formats

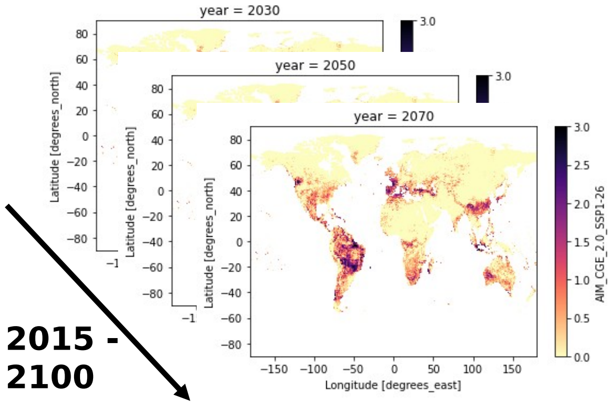
Spatial gridded netCDF forma

One IAM scenario, multiple indicators,

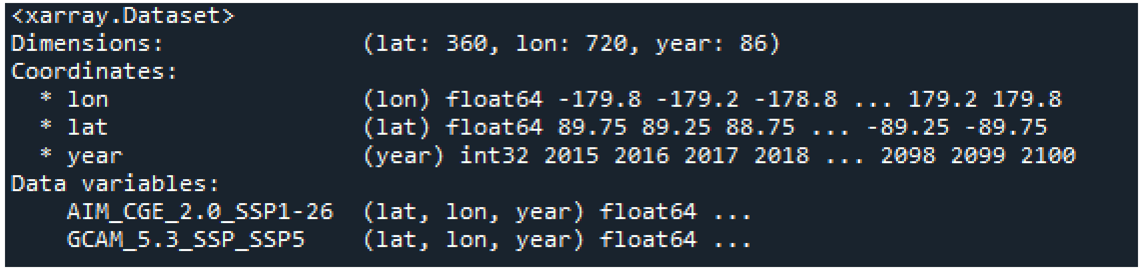


```
<xarray.Dataset>
Dimensions:      (lat: 360, lon: 720, year: 86)
Coordinates:
  * lon          (lon) float64 -179.8 -179.2 -178.8 -178.2 ... 178.8 179.2 179.8
  * lat          (lat) float64 89.75 89.25 88.75 88.25 ... -88.75 -89.25 -89.75
  * year         (year) int32 2015 2016 2017 2018 2019 ... 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

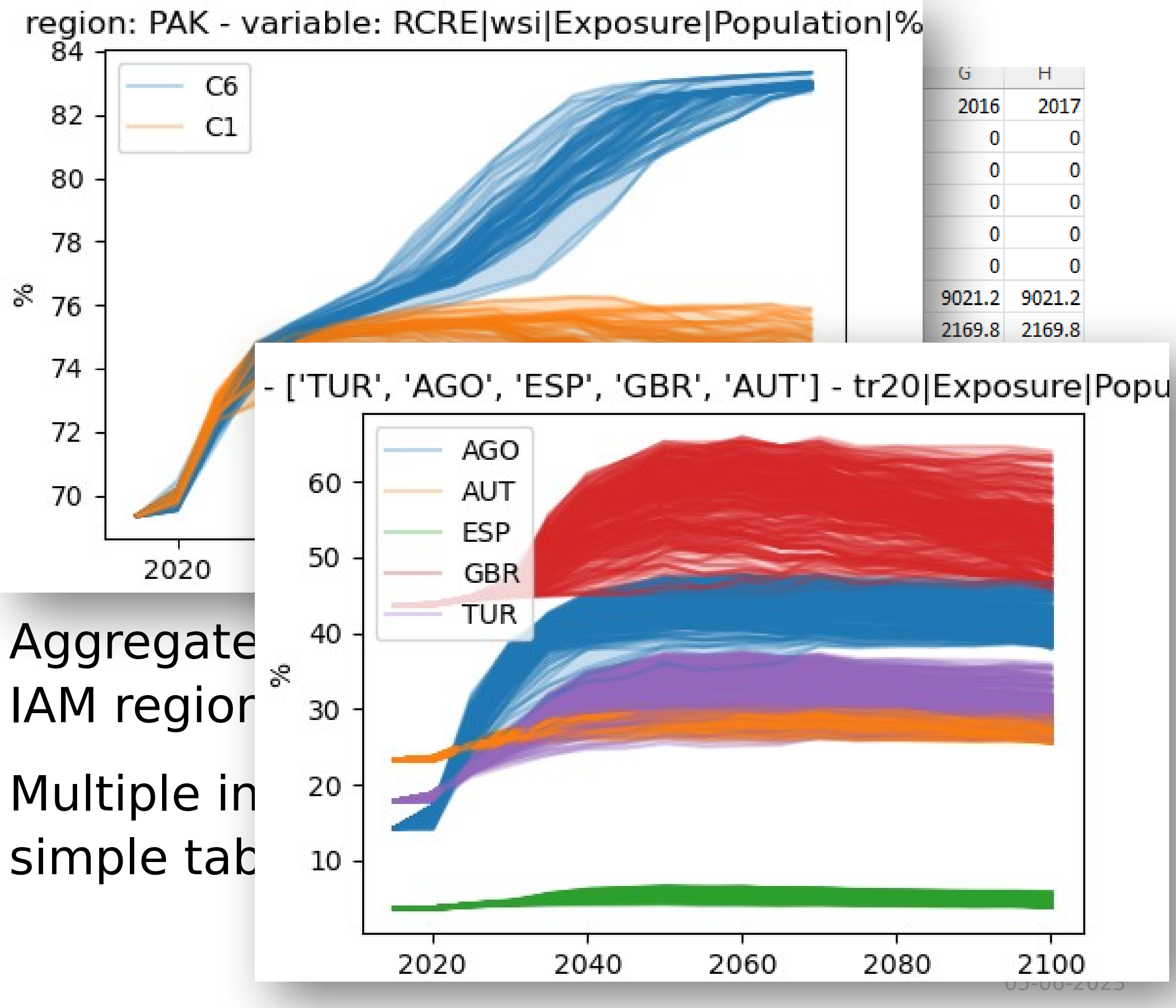


Multiple IAM scenarios, one indicator



```
<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 ...
```

IAMC tabular format



G	H
2016	2017
0	0
0	0
0	0
0	0
0	0
9021.2	9021.2
2169.8	2169.8

Aggregate
IAM regior

Multiple in
simple tab

Conclusions

1. Impacts integration into IAMs

- Test more impacts, e.g., hydrology, water supply, power supply, biomass potential (CDR)
- Apply similar methods to adaptation options
- Explore mitigation-adaptation synergies and tradeoffs
- Support climate impacts assessment of unknown emissions scenarios, including overshoot

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

Next steps

2. Rapid impacts emulation

- Various indicators prepared to develop database of gridded and country-level impacts and exposure
- Scripts for interpolation and re-indexing of datasets
    - Input: GMT trajectory by year (.csv)
    - Output: Impact indicators by year (.csv, netCDF)
- Developed in Python: Xarray + Dask parallelized processing. Fast for single scenarios – large ensembles like AR6 more difficult
- Extend to more indicators + vulnerability
- Launch open source
- Facilitate batch processing of IAM scenarios for online data processing and model intercomparison
- Support IPCC WG1-WG2-WG3 integration

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Implementation

python
xarray
pyam
pandas
dask
GitHub

Acknowledged support

IAMC Integrated Assessment Modeling Consortium Founded 2007
ISIMIP Inter-Sectoral Impact Model Intercomparison Project
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SPARCCLE
RITE Research Institute of Innovative Technology for the Earth
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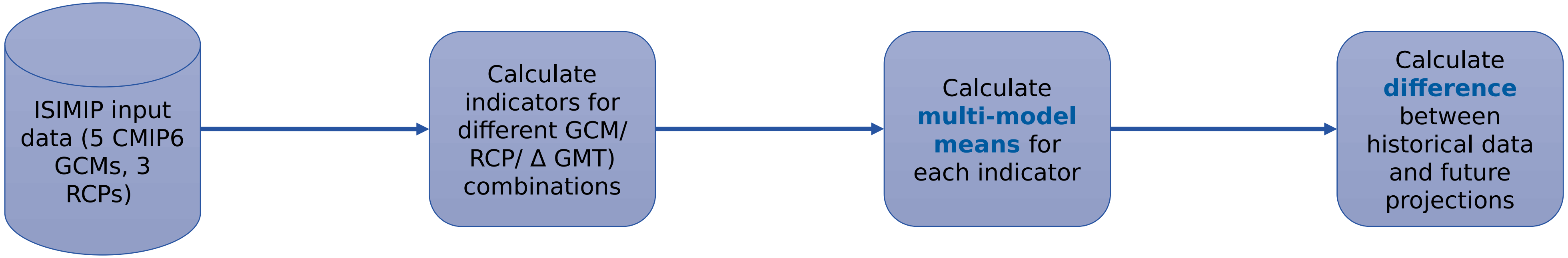
Workflow: Pre-processing impacts data

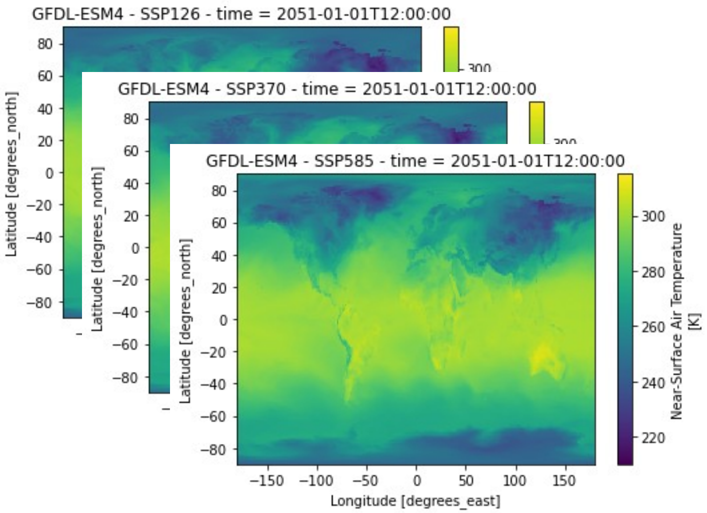


ISIMIP input data (5 CMIP6 GCMs, 3 RCPs)

Calculate indicators for different GCM/ RCP/ Δ GMT) combinations

Calculate **multi-model means** for each indicator

Calculate **difference** between historical data and future projections



Precipitation

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

Hydrology

- Drought intensity
- Seasonality
- Interannual variability
- Water stress

Temperature

- Heat wave intensity
- Tropical nights

Land

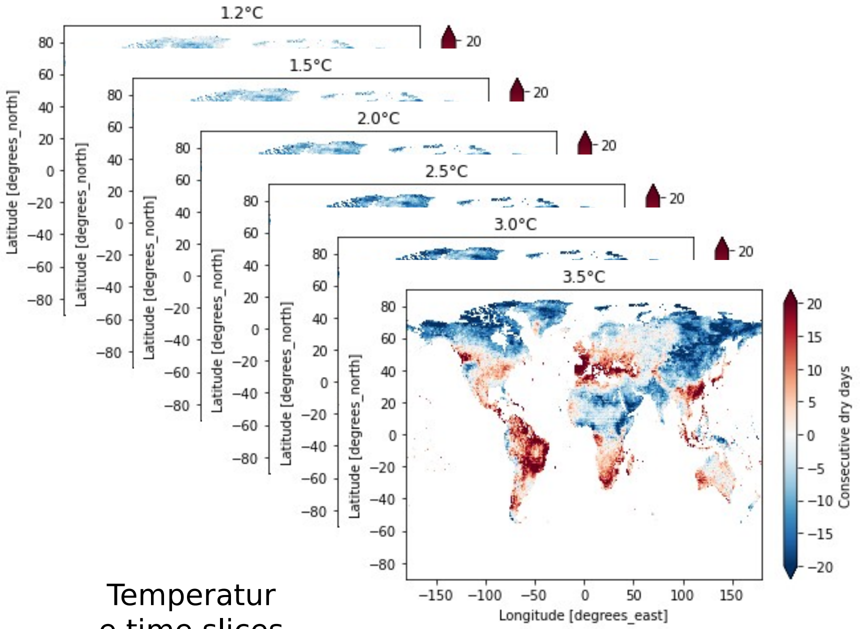
- Low intensity land cover
- Crop yields

Energy demands

- Cooling degree days

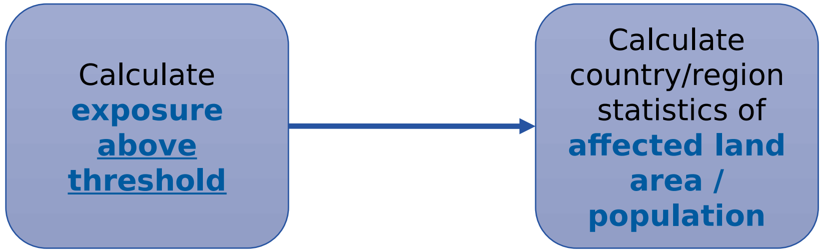
Air pollution

- Ambient PM2.5



Temperature time slices

Workflow: Calculate population & land exposure



Calculate **exposure above threshold**

Calculate country/region statistics of **affected land area / population**

Available statistics:

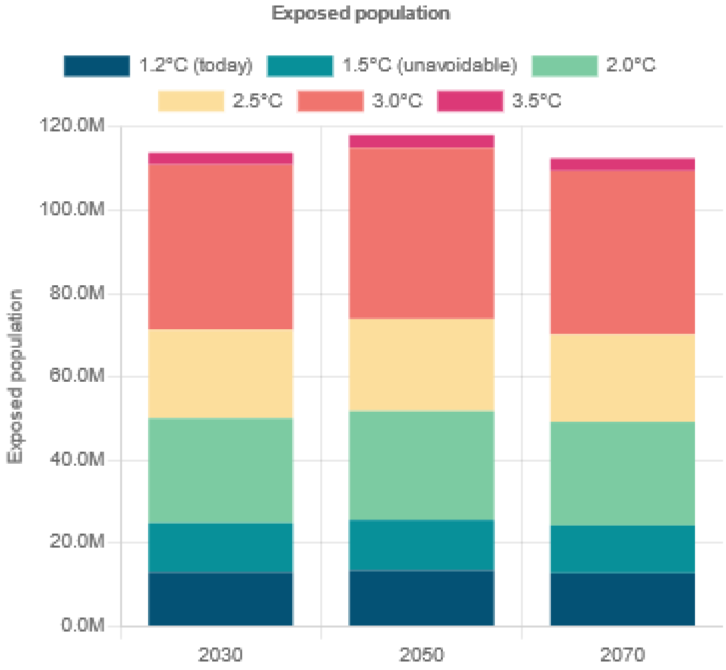
Hazard/Difference value for country/region

- weighted by population
- weighted by land area

Above threshold: e.g.
- Water stress index >0.3
- x% increase in Tropical Nights
- x% reduction in crop yields

Exposure statistics:

- Exposed land area
- Exposed land area %
- Exposed population
- Exposed population %
- + High/Low population ranges



Population exposed to consecutive dry days in Brazil