

# Climate Impact Explorer (CIE) 2025 Methodology

November 2025

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## Summary

The Climate Impact Explorer (CIE) provides direct access to projections of physical climate risks at regional, national and continental levels. It displays maps and time series illustrating projected changes in climate conditions and their resulting impacts at various levels of global warming.

In 2025, the Climate Impact Explorer underwent a major update, including updated and improved input datasets, an improved methodology, enhanced usability and a revised indicators list among other improvements.

The CIE provides projections for a selection of policy-relevant emissions scenarios, including those from the Network for Greening the Financial System (NGFS).

All projections assume that socio-economic conditions (population, land use, management practices, etc.) will remain constant as they were in 2020. Therefore, the CIE shows the isolated effect of climate change on impact indicators.

All displayed materials and the underlying data can be downloaded via the CIE interface.

*For a practical introduction to the CIE, please refer to the updated user guide, which uses illustrative use cases to explain central concepts.*

## Key functionalities of the updated CIE webtool

- Projections of the impacts of climate change at national and subnational levels on an annual and seasonal basis
- Uncertainty ranges combine the uncertainty stemming from varying global climate sensitivity to emissions, as well as the uncertainty regarding how local impacts respond to warming.
- Aggregation at regional, national and continental levels using weighted averages based on area, GDP or population.
- Time evolution of future impacts for scenarios from the Network for Greening the Financial System and the ‘current policies’ scenario in the Climate Action Tracker.
- A ‘high-warming world’ has been included with the 2025 update, i.e., a scenario-version of the NGFS Current Policy scenario based on the 20% of climate model simulations that result in the strongest plausible warming response for the same emission trajectory. This allows the assessment of risks resulting from a higher sensitivity of the climate system, which can be very relevant, for example, for stress testing exercises.
- Country maps for different warming levels containing information on the robustness of the projections based on the agreement between the various climate and impact models used to derive them (model agreement).

- The CIE features physical risks indicators across the categories climate, heat, drought, extreme precipitation, fire weather, freshwater, labour productivity and agriculture with projections until 2100.
- Improved heat stress and SPEI-based drought indicators as well as a variety of indicators that had not been covered in the previous CIE version are provided in the new CIE.
- The CIE allows to download all displayed graphs and maps, as well as the underlying data.

## Guidance on usage

The Climate Impact Explorer provides a globally comprehensive and consistent dataset of physical risk projections across climate scenarios. With a wide range of indicators, established down-scaling and bias correction, a consistent comparison across countries and regions is enabled. This allows an exploration of the different hazards for example for regional and sector specific analysis of climate impacts (e.g. comparison of exposure of different regions). Depending on the use case and regions, the data provided may be appropriate, whilst in other cases, higher resolution products, e.g., from regional climate models, may be available. Therefore, whilst the CIE may serve as a useful entry point or screening tool for climate risk, it is not a substitute for detailed national or subnational risk assessments.

*For a practical introduction to the CIE, please refer to the updated user guide, which uses illustrative use cases to explain central concepts.*

## Citation

You can use the data available on the Climate Impact Explorer if you acknowledge the source of the data by citing:

IIASA & Climate Analytics, 2025. Climate Impact Explorer. Available at: <https://climate-impact-explorer.climateanalytics.org/>.

Regarding the data sources we build on (ISIMIP), please check the potential copyrights on the corresponding websites or directly with the authors of the data.

## Acknowledgements

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We also would like to thank the following external contributors: Katja Frieler (Potsdam Institute for Climate Impact Research - PIK) and Christian Otto (Potsdam Institute for Climate Impact Research - PIK).

## 1 Methodology

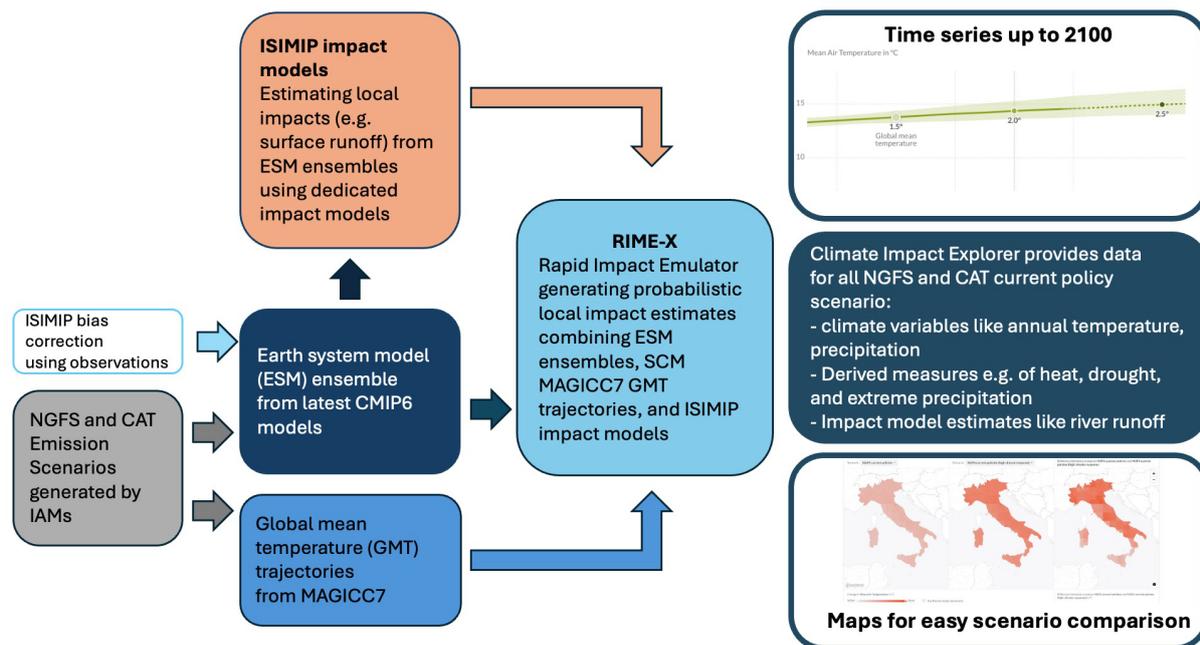
### 1.1 Core Concept and Overview of the Modelling Chain

The Climate Impact Explorer provides information on projected developments for various climate variables and impact indicators at different levels of global warming and how these changes may unfold over time under various greenhouse gas emissions scenarios. An overview of the modelling chain and data inputs used is given by Fig. 1 a & b.

This information is presented at country and regional level as a time series with 5-year intervals up to the year 2100, and in maps visualising projected changes: The tool enables users to visual a comparison at different levels of global warming (1.5°C, 2°C, 2.5°C, 3°C and 3.5°C) as well as between scenarios and years.

This information is derived from an ensemble of climate and climate impact models that have participated in international model intercomparison initiatives. The CIE demonstrates the outcomes of climate impacts for different emissions scenarios, providing the associated uncertainty ranges, including uncertainties in the global climate response to the emissions and in the regional implications of this global climate response.

The emissions scenarios for which impacts are projected were either derived from Integrated Assessment Models (IAMs) in collaboration with the Network for Greening the Financial System (NGFS) or produced by the Climate Action Tracker (CAT) based on policy analysis. Basic information on these scenarios can be found in section 2.1. For further details on the scenarios, please refer directly to the NGFS scenario portal (<https://www.ngfs.net/ngfs-scenarios-portal/data-resources>) or the technical documentation (<https://www.ngfs.net/en/publications-and-statistics/publications/ngfs-climate-scenarios-central-banks-a>



(a) Modelling flow of the 2025 Climate Impact Explorer



(b) Data sources for the 2025 Climate Impact Explorer

**Figure 1 - CIE Modelling Chain and Data Sources**

In this Section 1, we provide information on the subsequent methodological steps implemented in the open-source probabilistic Rapid Impact Model Emulator RIME-X (illustrated in Fig. 2):

- section 1.2 describes how the simple climate model MAGICC7 is used to generate an ensemble of Global Mean Temperature (GMT) trajectories for the different emissions scenarios.
- section 1.3 elaborates how data from bias-corrected earth system models (ESMs) from the latest coupled model intercomparison project CMIP6 and impact models from the Inter-Sectoral Impact Model Intercomparison Project ISIMIP3 are combined to provide indicator projections. For this, the rapid impact model emulator RIME-X is used to generate distributions of local impact indicators given a specific global warming level, assuming that local indicators mainly depend on Global Mean Temperature.
- section 1.4 describes how to combine the ensemble of GMT trajectories from MAGICC7

with the conditional distributions of local indicators to model the full distribution of the local indicator across all timesteps of the scenario. This comprehensive probabilistic approach allows for the integration of all sources of uncertainty without the need to estimate uncertainty ranges as in previous versions of the CIE.

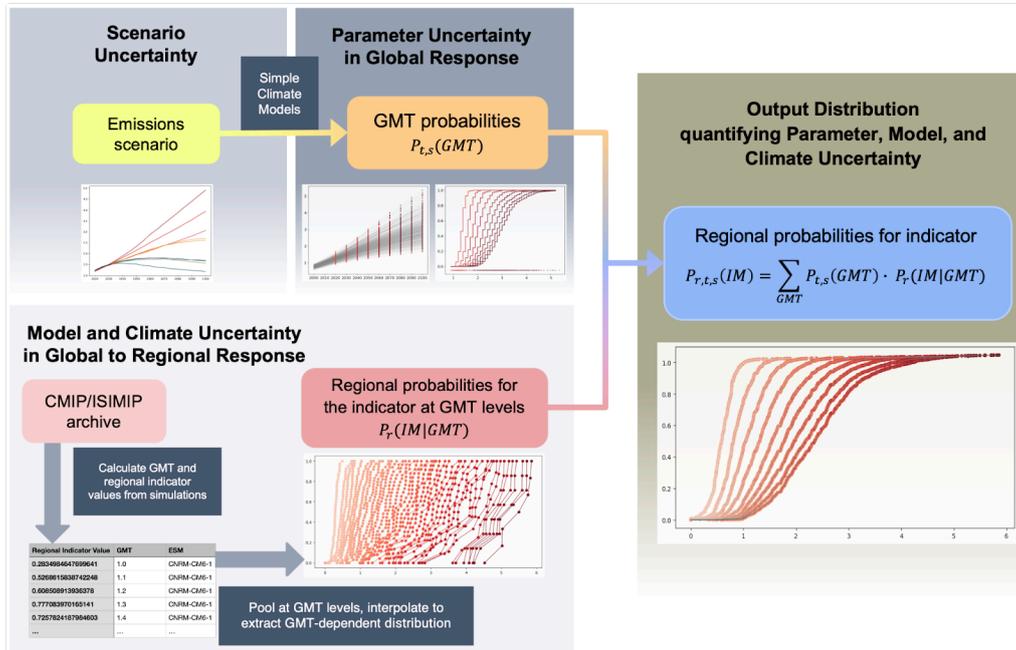


Figure 2: Summary of RIME-X processing steps (Schwind et al. 2025)

Data processing and weighting schemes are described in section 1.6.

section 2 describes the emissions scenarios on which the CIE builds, the ISIMIP database, and the climate models that contributed to them.

section 3 introduces the various options for visualisations in the CIE.

## 1.2 Global Mean Temperature (GMT) Projections

To project Global Mean Temperature, the CIE uses various scenarios describing emissions pathways. The scenarios are the NGFS scenarios from REMIND-MAGPIE covering different warming levels, complemented by the Climate Action Tracker (CAT) current policy scenario.

These emissions pathways are the input to the Simple Climate Model (SCM) MAGICC - Model for the Assessment of Greenhouse-gas Induced Climate Change (Meinshausen et al., 2011).

MAGICC simulates Global Mean Temperature (GMT) projections from those emissions pathways using simplified representations of climate system components, calibrated with a plausible range of parameters. Varying these parameters allows for the generation of a probabilistic ensemble of plausible GMT trajectories for each emissions pathway.

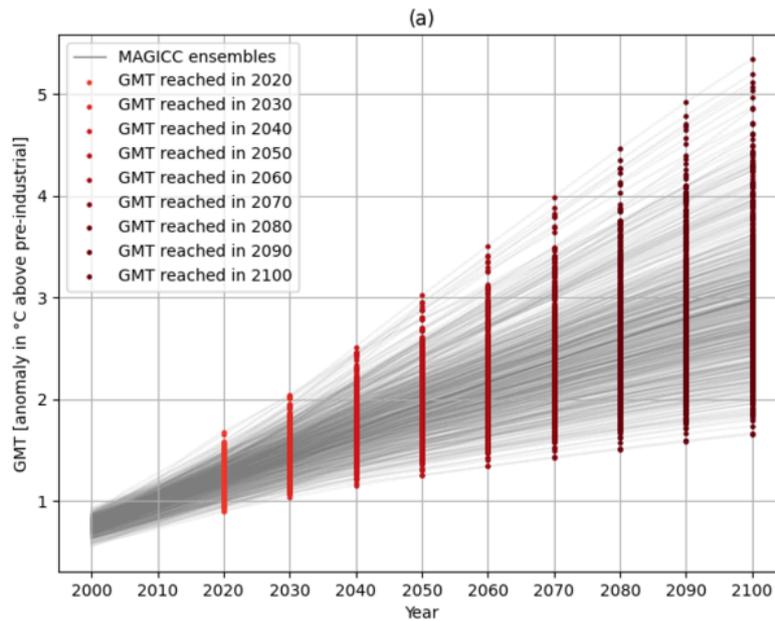


Figure 3: Projected GMT trajectories corresponding to the emissions pathway that currently implemented policies on global emissions reduction are set to meet, according to the REMIND-MAgPIE model (NGFS Current Policies Scenario). The different paths show the 600 ensemble members from the MAGICC7 simulation (Schwind et al. 2025)

To allow for the comparison of scenarios based on warming levels, the MAGICC outputs are adjusted to match the warming estimate between the period 1850-1900 and 2011-2020 of 1.09°C, based on IPCC AR6 (see Table 1 of Cross-Chapter Box 2.3, Gulev et al., 2021). The adjusted GMT ensembles are used as an input to estimate changes in local estimates using RIME-X.

Updates compared to CIE 2024:

- RCP pathways are no longer included in the updated CIE.
- All emissions pathways used in the CIE are now consistently based on MAGICC 7.

### 1.3 Mapping GMT trajectories to local changes in climate impacts

To map GMT trajectories to local changes in climate indicators, we assume that indicators can be projected as a function of GMT level. The central assumption of this approach is that the distribution of local indicators mainly depends on GMT levels, irrespective of when in time or in which emissions scenario the GMT level is reached. This approach is grounded in scientific literature (James et al., 2017) and uncertainties are small compared to the spread between models (Herger et al., 2015). The approach represents however an approximation and does not account for effects such as hysteresis, i.e. the possibility that some components of the climate system exhibit a different response to temperature changes depending on the direction of change (one slow-onset example being ice sheets (Garbe et al., 2020)).

To map the GMT trajectories to local changes in impacts, bias corrected earth system model (ESM) data from CMIP6 and resulting impact projections from ISIMIP3b are utilised.

The CIE is based on ESM simulations for the historical period from 1980 on and several SSP simulation runs (by default SSP1-2.6, SSP3-7.0, and SSP5-8.5 and SSP2-4.5 and SSP4-6.0 for some indicators).

Indicators in the Climate Impact Explorer are expressed as absolute values or as relative differences compared to the values in the 1996-2014 reference period (for the indicators derived from ISIMIP data, see 2.2).

These changes were simulated in scenario experiments conducted either by ESMs or IMs (using ESM outputs as input data).

Pooling these estimates of changes in indicators for ranges of GMT levels, allows to project indicators for any scenario that reaches these levels. To this end, the novel mapping method RIME-X (Schwind et al. 2025) identifies the points in time at which each GMT bin is reached, and maps them to the computed change in impact indicator.

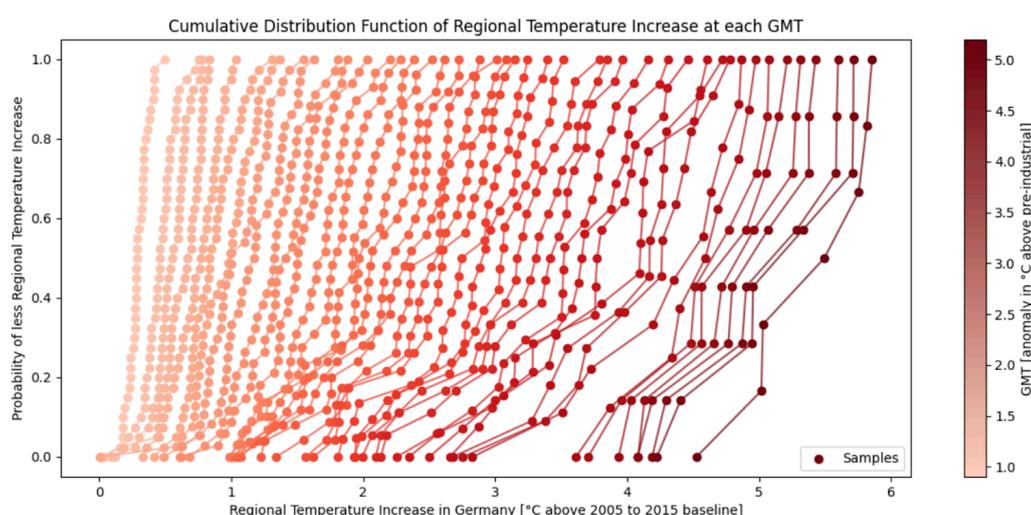


Figure 4: Estimation of Regional Temperature Increase at each GMT level for the example of Germany (Schwind et al. 2025)

Caveats:

It is important to note that our confidence in the results decreases for high levels of warming (particularly beyond 2.5 - 3 °C of global warming), since these levels are based on a lower number of model runs.

#### Updates compared to 2024:

- Use of latest model generation of CMIP6 and ISIMIP3
- Using improved mapping method RIME-X (Schwind et al. 2025)
- Increased ensemble size from 4 climate models to at least 5 primary ISIMIP ESMs, for most indicators 14 primary and secondary ISIMIP ESMs.

#### 1.4 Comprehensive uncertainty assessment using RIME-X

Using the above described method - RIME-X (Schwind et. al 2025 - for combining projected GMT trajectories from simple climate models and projections of local impacts at varying GMT

levels based on earth system models allows for a more comprehensive uncertainty modelling approach.

Three types of uncertainty have to be considered in the mapping of GMT levels to local impact indicators:

1. GMT level trajectories from SCMs contain parameter uncertainty
2. Earth system models result in model uncertainty
3. Within complex climate models, climate uncertainty remains

**Parameter uncertainty of SCMs:** Since SCMs rely on the parametrisation of climate processes to project GMT levels, their results depend on the exact choice of parameters. By using 600 plausible parameter combinations generated based on IPCC assessed ranges for equilibrium climate sensitivity (ECS), MAGICC7 generates an ensemble range of GMT projections for each emissions scenario, with each ensemble member being equally likely to describe the real GMT response to emissions.

**Model uncertainty in ESMs:** Comparing different ESMs, there is variation in projected warming (as characterised by varying climate sensitivities and resulting regional changes driven by a certain emissions pathway. In our method this uncertainty mainly translates into uncertainty of how global climate change characterised by global mean temperature translates into regional indicators.

**Climate uncertainty within ESMs:** Even within a set of simulations from one ESM, natural variability and varying initial conditions may result in different local indicator values at similar GMT levels.

RIME-X addresses these uncertainties in each step of the mapping process.

1. Mapping scenario emissions to a GMT distribution includes parameter uncertainty from MAGICC7, providing a mapping of emissions scenarios to GMT levels.
2. The extraction of regional indicator values for ranges of GMT addresses model and climate uncertainty, resulting in a distribution of regional indicator values conditional on GMT levels.
3. Combining the mapping of emissions to GMT and the GMT conditional distribution of indicator values to provide the final CIE data thus includes all types of uncertainty in one comprehensive estimate.

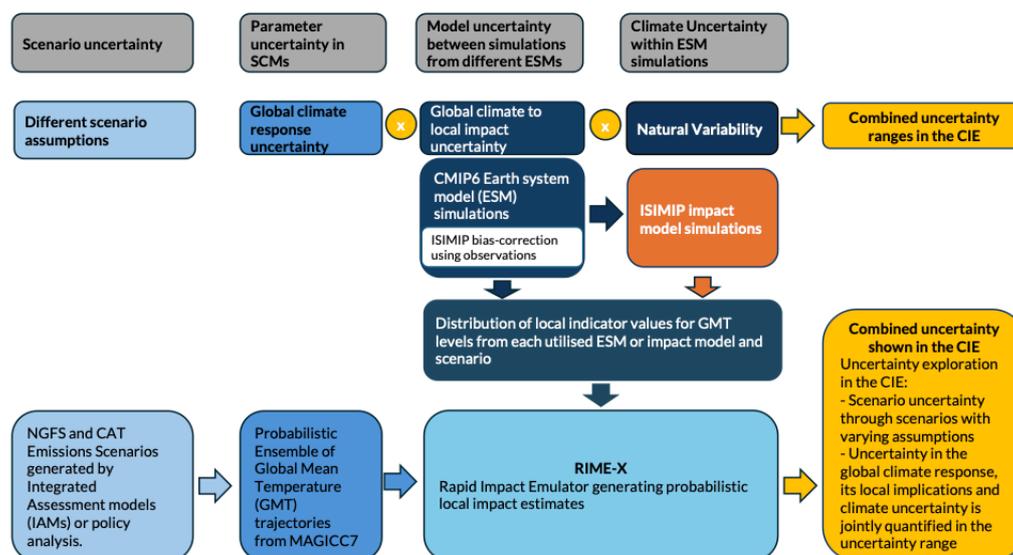


Figure 5: Schematic overview of the combined types of uncertainties stemming from the global mean temperature and the local impact response

#### Updates compared to 2024:

- Use of latest model generation CMIP6 and ISIMIP3
- Using improved mapping method RIME-X (Schwind et al. 2025) instead of quantile regressions or linear estimation of uncertainties
- Increased ensemble size from 4 climate models to 5 primary ISIMIP models, 14 primary & secondary models for most climate indicators and some impact models
- Increased number of emissions scenarios considered in RIME-X - 3 default RCPs + historical scenario instead of 2 default RCPs

### 1.5 High climate response scenario to account for uncertainty in the global climate response

There is a wide range of physically possible global warming outcomes (determined by the spread in climate response, see Chapter 1) for a given emissions pathway.

A higher global climate sensitivity would lead to *faster and stronger* global warming for the *same* emissions trajectory and thus also much stronger climate impacts and damages already in the near-term. This newly introduced scenario-version of the NGFS Current Policy scenario is based on the 20% of climate model simulations that result in the strongest plausible warming response for the same emission trajectory. We suggest that such an outcome would need to be considered by regulators for physical stress testing purposes, as accounting of these risks is essential for the financial sector and the economy at large.

We therefore also show projected climate impacts for a *“high climate response world”* as a plausible future. The NGFS Current Policies emissions scenario is used as base to present the global warming outcome assuming a high climate response world. To obtain this we only consider the upper 20 percent of the MAGICC model’s output ensemble for the construction of the scenarios’ GMT response - thus considering a 1-in-5 chance of these higher warming

outcomes occurring. In total, this means we focus on 120 ensemble members showing the highest end of century global mean temperature increase from the 600 member ensemble of the MAGICC model.

Note that this approach does not consider global to regional climate uncertainties. The reason for this is that regional climate uncertainties are variable and model dependent (i.e. over a certain region, one Earth System Model might project a particularly pronounced drying trend vs. another projects stronger increases in extreme precipitation). By focussing on a higher climate response world, however, we modulate the key driver variable of our ensemble thereby providing an internally consistent set of CIE climate impact indicators, but for a high physical risk world outcome.

**The CIE Update allows exploring the differences between the “best estimate” and a “high climate response world”.** To provide a “best estimate” and uncertainty band for the projected climate impacts, the Climate Impact Explorer takes into account i) all possible global climate responses (i.e. translating emissions into GMT projections) and ii) all values modelled for the projected climate impact by simulations participating in ISIMIP3b at global climate states possible in the scenario.

**Where to find this “What-if high climate response world” in the CIE?** In the scenario selection, this scenario is provided under the name “NGFS current policies (high climate response)”. The high climate response option serves to illustrate climate impacts in cases where the climate response to emissions is at the upper end of expected warming response from MAGICC7 pathways. For this, only the 20 percent upper possible climate responses from the MAGICC7 ensemble are used. These additional “what-if”-scenario-versions are available for the NGFS Current Policies Scenario.

## 1.6 Further data processing

**Masking of grid cells for specific variables** For the fire weather index, water stress index and annual drought intensity, desert and ice areas were masked out using Sellers et al. (1996) and GWSP2 data.

For the SPEI index, an agricultural harvest area mask was used based on Proctor et al. (2022).

**Temporal averages** For most impact indicators, changes in annual mean as well as seasonal mean values were calculated. The considered seasons were: December-January-February (DJF), March-April-May (MAM), June- July-August (JJA), and September-October-November (SON).

**National or subnational level averages** Eight different spatial aggregation methods have been used to derive the time series that can be visualised in the CIE.

For many indicators, the user can choose between three spatial weighted averaging methods: by area, population or GDP. To derive area-weighted averages, each grid cell is weighted by the fraction of the land area of the selected territorial unit it covers. For population or GDP weighted averages, each grid cell is weighted by the fraction of the population or GDP of the

selected territorial unit located in the grid cell. For grid cells that do not fully lie within a territorial unit, the population or GDP of the grid cell is scaled to the fraction of the grid cell that is covered by this territory. We use the gridded population data corresponding to year 2020 provided by WorldPop (described in Lloyd et al., 2019) and the GDP dataset corresponding to the year 2020 from Kummu et al. (2025), assuming that the repartition of population and GDP within a country will stay constant in the future.

Due to its relevance for agriculture for the “Area under [drought level] drought” indicator we additionally offer a spatial averaging method weighted by the combined harvest area of wheat, soybean and maize. For each agricultural yield change indicator spatial averaging method weighted by the yields of the corresponding crop in the corresponding gridpoint in the baseline period. The baseline data was obtained from MIRCA2000.

## 2 Models, scenarios and data sources

### 2.1 Emissions scenarios

The CIE provides data indicating how climate impacts unfold over time under various scenarios of greenhouse gas emissions. These emissions scenarios are derived with Integrated Assessment Models (IAMs) in collaboration with the Network for Greening the Financial System (NGFS) or based on policy analysis based on the Climate Action Tracker.

**NGFS Scenarios** In collaboration with the NGFS, a consortium of international research institutes has developed a set of climate scenarios to serve as a reference framework for central banks. The NGFS Climate Scenarios provide a basis for analysing the risks that climate change poses to the economy and financial system. They are developed with central banks, but can be applied more broadly to the financial sector and economic risk assessments.

The CIE provides impact data on climate variables and extreme events for all seven NGFS scenarios:

- **Current Policies:** This scenario assumes that only the climate policies currently in place are maintained, with no further strengthening. Global greenhouse gas emissions continue to grow until 2080, resulting in approximately 3°C of warming and irreversible changes such as increased sea level rise. In NGFS terminology, this is a ‘hot house’ scenario characterised by high physical risks and low transition risks.
- **Net-Zero 2050:** This ambitious scenario involves the immediate introduction of stringent climate policies and innovation to limit global warming to 1.5°C, with net zero CO<sub>2</sub> emissions being reached globally around 2050. Some jurisdictions, such as the US, the EU and Japan, will have reached net zero for all greenhouse gases by this point. Carbon dioxide removal (CDR) is used to accelerate decarbonisation, but is kept to a minimum and is broadly in line with sustainable levels of bioenergy production. Physical risks are relatively low, but transition risks are high.
- **Fragmented World:** This scenario assumes delayed and divergent climate policies among countries, leading to high physical and transition risks. Countries without zero

targets continue with current policies, while others only partially achieve their targets (80%).

- **Nationally Determined Contributions:** This scenario includes all pledged targets, even those not yet backed up by effective policies.
- **Below 2 degree:** This scenario involves a gradual increase in the stringency of climate policies, providing a 67% chance of limiting global warming to below 2°C.
- **Low Demand:** This scenario assumes significant behavioural changes that reduce energy demand and mitigate pressure on the economic system to achieve net zero CO<sub>2</sub> emissions globally by around 2050.
- **Delayed Transition:** This scenario assumes that no new climate policies will be introduced until 2030. The level of action differs across countries and regions based on the policies currently in place, leading to a ‘fossil recovery’ from the economic crisis brought about by the pandemic. It is assumed that the availability of carbon dioxide removal (CDR) technologies will be low. Therefore, global emissions will decline very rapidly after 2030 in order to ensure a 67% chance of limiting global warming to below 2°C by 2100. This results in higher transition and physical risks than in the Net Zero 2050 scenario, but lower physical risk than in the Current Policies scenario.

In the CIE, impacts are only shown based on emissions pathways simulated by REMIND-MAgPIE.

Further details on these scenarios are available on the NGFS Scenarios Portal or the NGFS IIASA Scenario Explorer.

### Updates compared to 2024:

- None of the scenarios changed but the “high climate response” scenario was added. This scenario is not an official NGFS scenario but bases on above mentioned “current policies” scenario.

**Scenarios from the Climate Action Tracker** The Climate Action Tracker (CAT) is an independent scientific project that tracks and measures government climate action against the globally agreed aim of the Paris Agreement: “to hold the increase in the global average temperature well below 2°C above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5°C”. Led by Climate Analytics and the New Climate Institute, the CAT has been providing this analysis to policymakers since 2009.

The CAT quantifies and evaluates climate change mitigation commitments from the largest emitters, as well as a representative sample of smaller emitters, covering around 80% of global emissions and approximately 70% of the global population. It then assesses whether countries are on track to meeting these commitments.

In the CIE, we present the projected impacts of an emissions scenario known as ‘Current Policies’, which reflects the projected effects of the policies implemented or enacted by the

governments of the analysed countries and their likely impact on national emissions until 2030 and, where possible, beyond.

The CAT then aggregates this country-level action to determine a likely global mean temperature (GMT) trajectory by the end of the century, as well as the associated uncertainty range, using MAGICC7 (see section 1.2).

### Updates compared to 2024:

- Updated to CAT data from 2024 using MAGICC7

## 2.2 ISIMIP data

The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) is a community-driven initiative that aims to provide a consistent framework for modelling the impact of climate change.

By late 2025, the ISIMIP initiative had received contributions from more than 100 models. To participate, impact modelling teams agree to run a minimal set of model experiments. These include scenario experiments simulating the evolution of sectoral impact variables until at least 2100 under specific climate and socio-economic forcing trajectories. The corresponding input data, based on Earth system models (ESMs), is provided for these experiments. The resulting output data become open access after an embargo period and can be downloaded from data.isimip.org. The CIE displays input data (Table 3) and output data (Tables 4 and 5) from Phase 3b of ISIMIP (ISIMIP3b) at a spatial resolution of 0.5° (equivalent to ~50 km at the equator and decreasing further as one moves poleward). Users should bear this spatial resolution in mind when interpreting the graphs and maps displayed on the Climate Impact Explorer, particularly when viewing small areas such as small island states.

The ISIMIP3b climate input data were obtained from the sixth phase of the Coupled Model Intercomparison Project (CMIP6) using 5 primary, and for some impact model 9 additional secondary GCMs. These data have been bias-adjusted, meaning that the differences between the values simulated by each GCM and the values observed over a common period have been corrected and applied to the entire simulated period.

**ISIMIP3b bias adjustment and statistical downscaling** The ISIMIP3b bias adjustment process corrects systematic errors in climate model outputs, making them more comparable to observed climate data. This is essential to provide climate projections for impact studies.

**Reference Dataset and Reference Time Periods:** Bias adjustment in ISIMIP3b uses the WFDE5 dataset as the observational reference. WFDE5 is based on ERA5 reanalysis, further corrected with ground observations to improve accuracy, especially for temperature and precipitation.

**Reference period:** The training period for bias adjustment is 1979 - 2014, chosen for its comprehensive and high-quality global coverage.

**Statistical downscaling:** - Data already at 0.5° resolution were bias-adjusted using W5E5 data at 0.5° spatial resolution - Data at 1.0° resolution were first bias-adjusted using W5E5 data aggregated to 1.0° and then downscaled to 0.5° using W5E5 data at 0.5° spatial resolution

- Data interpolated to 2.0ř were first bias-adjusted using W5E5 data aggregated to 2.0ř and then downscaled in two steps using W5E5 data at 1.0ř and 0.5ř spatial resolution.

**Method of Adjustment for Variables:** The bias adjustment methods are tailored to each variable, as summarized in the fact sheet's table: - Temperature (daily, minimum and maximum): Adjusted using quantile mapping, which aligns the distribution of model data with observations for each calendar month. - Precipitation: Uses quantile mapping with additional corrections for wet-day frequency and intensity, addressing common model biases in rainfall occurrence and amount. - Other variables (e.g., wind speed, humidity, solar radiation): Methods vary, but generally involve distributional mapping and corrections for physical consistency.

**Physical consistency:** Adjustments are performed separately for each variable, which may affect relationships between variables (e.g., temperature and humidity).

**Robustness / Validation Results:** Validation shows that bias adjustment improves the match between model outputs and observations, especially for temperature and precipitation.

**Caveats:**

- Assumes bias patterns are stationary over time, which may not hold under strong climate change.
- Adjusting variables independently can affect their physical relationships.
- Extreme events may still be underestimated.

For more information, please refer to the ISIMIP3b Bias Adjustment Fact Sheet.

Unlike indicators derived directly from climate variables, the sectoral impact indicators displayed on the CIE did not undergo a bias-adjustment or validation procedure. While such validation would be highly desirable, it is generally challenging at a global level due to a lack of data on both biophysical quantities and other human interventions (e.g. flood protection dikes, forest management and groundwater extraction for irrigation).

**Caveats:** Although information is provided at country level, not all impact models have been evaluated and validated for each country. Importantly, the CIE provides information on the effects of climate change alone, as indicated by the available ISIMIP-derived indicators. In order to isolate changes in risk due to climate change, the CIE assumes that socio-economic conditions remain constant (e.g. population, GDP, water use). In reality, however, socio-economic development will have a significant impact on future developments.

### Updates compared to 2024:

- ISIMIP3b instead of ISIMIP2b data based on CMIP6 instead of CMIP5
- Increased number of GCMs from 4 to at least 5 primary, for many indicators 14 primary and secondary models from ISIMIP3b
- Improved bias adjustment method within ISIMIP

### 2.3 Additional derived indicators

For a complete overview of the indicators available in the CIE, please check the Indicator Reference Table available online.

Adding to the ISIMIP output variables that are readily available, we calculate various extreme event indicators to allow for an initial assessment of changes of extreme weather events based on annual severity of events. These indicators should be followed up by more localised studies based on higher time resolutions - ideally daily or higher - to consider potential temporal effects like compounding of impacts or regional seasons with elevated risks.

**Extreme Precipitation Indicators** We calculate the extreme precipitation variables Annual maximum daily precipitation and Annual maximum 5-day precipitation from the daily precipitation output variable (pr) using the following processing steps:

1. (For Annual maximum 5-day precipitation) We compute a rolling sum of daily precipitation values for each day in the dataset using precipitation data from two days prior until two days after the target day.
2. We determine the annual maximum among the resulting sums.

We additionally generate the Extreme Precipitation Indicator “Total Precipitation from Extreme Precipitation Events” which is defined as the annual sum of daily precipitation values that exceed the 99.9th percentile of daily precipitation values in the 1980-2015 reference period. The indicator jointly quantifies intensity and frequency increases of extreme precipitation events and is used as a proxy indicator for economic damages from climate change in the Kotz et al., 2024 damage function. The indicator “Heavy Precipitation Days” counts the days a year with more than 10mm of precipitation.

We generate the extreme precipitation indicators for all primary and secondary ISIMIP3b daily precipitation simulations.

**Drought Indicators** Globally changing drought frequency and severity constitute a major risk to agricultural production and food security with implications for national and worldwide economies. In the CIE we quantify drought using the 12-month Standardized Precipitation Evaporation Index (SPEI-12), a widely employed measure for persistent drought conditions (Araújo et al., 2025; Vicente-Serrano et al., 2010). We obtain this indicator for every primary ISIMIP3 climate input model (Frieler et al., 2024). SPEI-12 serves as a proxy for deep-layer soil moisture dynamics (Wang et al., 2019; Xu et al., 2021) and is therefore particularly suitable for assessing impacts on agricultural production. It is calculated by accumulating the water balance ( $D = P - PET$ ) over the preceding 12 months, where precipitation (P) represents water supply and potential evapotranspiration (PET) represents atmospheric moisture demand. We further use the SPEI-12 indicator to obtain the Area under moderate, severe, extreme, or very extreme drought indicators. We thereby consider a gridpoint to suffer from moderate, severe, extreme, or very extreme drought conditions if the SPEI-12 threshold of -1, -1.5, -2, or -2.5 is undercut in the gridpoint in at least one month.

We additionally offer three more proxy indicators linked to drought:

- The indicator Consecutive Dry Days counts the longest continuous period in a year where daily precipitation of under 1 mm.
- The indicator Annual Drought Intensity is the proportion between daily volume deficit of discharge below the 10th percentile daily discharge (Q90) of the reference period (1981 - 2014) and the duration of the deficit.

- The indicator Water Stress Index is the fraction between net human water demands (domestic, industrial, irrigation) and renewable surface water availability, and in this case is the same as the withdrawal to availability ratio.

**Heatstress indicators** For estimating impacts from extreme heat we employ the Heat Index (HI) a widely used and well studied metric for quantifying human heat stress from the combined effects of air temperature and relative humidity (Gosling et al., 2014; Anderson et al., 2013). Compared to indicators based on the commonly used Wet-bulb Globe Temperature (e.g., Clark & Konrad, 2024, we find that the HI exhibits a higher sensitivity to heat stress in moderate to dry climates (Langer & Kornhuber, 2025, which can have considerable health implications (see 66,000 estimated deaths during the 2022 European heatwave; Ballester et al., 2023 and is therefore more universally applicable. In addition, the new index features a higher temporal accuracy by estimating the most severe heat stress levels during the hottest hour of the day, which can be considerably higher compared to daily average values. This increased accuracy is achieved by physically approximating the humidity level at the time when the maximum daily temperature is reached from the daily average humidity values provided in ISIMIP3 (Bolton 1980, calculating the HI using this humidity value and the maximum daily temperature value and applying an additional bias correction to the heat index values of ERA5 to the output values.

In the CIE the daily maximum heat index values are calculated for the 5 primary ISIMIP3b simulations. Applying the thresholds of 26.6, 32.2, 40 and 51.6 degrees for the maximum daily heat index value defined by NOAA results in the days per year with emerging, high, dangerous and very dangerous heat risk. The CIE additionally provides 4 more heat indicators calculated from the primary and secondary ISIMIP3b input simulations:

- Cooling degree days, the annual sum of daily temperature values above the 26 degree threshold
- a proxy variable for the amount of energy needed for cooling.
- Consecutive Tropical Nights, the maximum number of consecutive nights where the temperature stays above 20 degrees.
- Annual Maximum Daily Temperature
- Daily Maximum Wet Bulb Temperature, another popular proxy indicator for heat stress we approximated from daily average relative humidity and daily maximum temperature using the method from Stull 2011.

Existing peer reviewed damage functions additionally allow for a conversion of heatstress levels to labor productivity losses (Foster et al. 2021 for more reliable projections of future economic damages from heat stress changes.

**Wildfire risk indicators** New indicators for Wildfire risks are introduced with the CIE 2025:

Underlying Fire Weather Index as defined by the Canadian Forest Fire Weather Index System, integrates temperature, humidity, wind speed, and precipitation to describe potential fire intensity.

**Number of days with extreme fire weather (FWIXD):** Calculated as the local annual number of days above the local threshold. The local thresholds are defined as the 95th percentile

of the FWI over the 1974-2005 historical period. FWIXD captures the number of days in a year with extreme fireconductive weather conditions.

**Length of the fire season (FWILS):** Calculated as the number of days in a year where the FWI values are greater than the mid-point value between the maximum and minimum FWI over the historical reference period (1974-2005). FWILS quantifies the length of time of fire-conductive conditions, reflecting changes in the duration of the fire-prone period.

## 2.4 Complexity classification of indicators

Due to their inherently diverse nature of acute and physical risk indicators and the need for providing for a comprehensive coverage of the climate risk landscape, indicators included in the CIE are subject to different levels of uncertainty, validation and input assumptions. Some are locally validated, while for others global validation data does not exist and assumptions about future adaptation and socio-economic development can strongly influence the results. Given the broad use of CIE indicators for different applications, a three level categorization is used, in which variables and indicators are categorized on the basis of their modeling complexity. The approach is illustrated in Fig. 6.

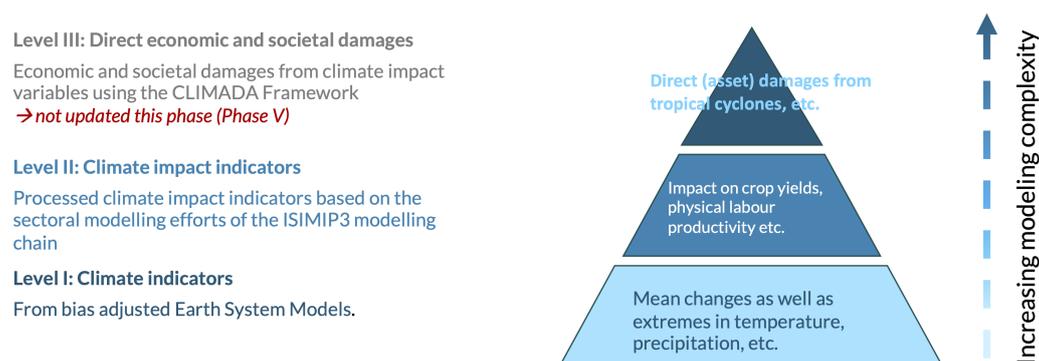


Figure 6: A hierarchical categorization of physical risk indicators and variables with complexity from top to bottom: Level I. Climate indicators from bias adjusted earth system models (e.g. number of hot days); Level II. Climate impact indicators based on ISIMIP modeling efforts (e.g. crop yields); Level III. Economic and societal damages based on the CLIMADA framework (e.g. asset damages from tropical cyclones)

As these indicators and variables represent the output from different steps of an evolving modeling chain, they form a natural hierarchy (Fig. 6), in which uncertainties and assumptions increase with each step.

### Level I - Climate indicators from bias adjusted earth system models (CMIP)

Level I Climate indicators are directly based on Earth System Models and are in part in direct correspondence to the physical variables which are bias adjusted and consistently downscaled within the ISIMIP3 project. The confidence in the level I indicators can be considered highest as uncertainties and required assumptions are typically lower. The lower overall underlying model complexity as well as the bias correction allows higher confidence in directly applying level I data for own analyses of CIE users. Table [T\_ind\_ov] provides information on which CIE indicators are categorized as Level I.

## **Level II - Climate impact indicators based on sectoral impact modeling efforts (e.g. ISIMIP)**

Level II Climate impact indicators are the outcome of the ISIMIP3 modelling chain. In contrast to the level 1 indicators deriving from ESMs, these more sophisticated models such as agricultural or hydrological models for flood and yield estimates respectively. For level II indicators, i.e. `_climate_impact_` indicators, the additional layer of complexity and uncertainties coming from the impact modeling (typically multiple impact models) is additional to the modeling complexity and uncertainty related to the level I climate indicators used as inputs. Even when some of the input climate variables have been bias corrected, the outcome of the impact modeling is typically not bias-corrected and not validated, or potentially only for selected regions. When working with level II indicators, users should make themselves familiar with the limitations as outlined in the technical documents and disclaimers on applicability when applying the data and interpreting the results. Table [T\_ind\_ov] provides information on which CIE indicators are categorized as Level II.

## **Level III - Direct economic and societal damages**

Level III indicators, i.e. those related to economic damages, are subject to a range of additional modeling complexity and socio-economic assumptions which adds to the above described complexity and modeling uncertainty ranges. Especially the underlying socio-economic assumptions typically have a normative dimension. As a consequence, the level III *economic damage* indicators are of a more indicative nature, which the CIE user should be aware of when using or interpreting the data. Please note that the level III indicators (i.e. economic and societal damages) have not been updated due to resource constraints.

## **Updates compared to 2024:**

- The above described classification was introduced.

## **2.5 Providing absolute values for selected indicators additional to relative changes**

As in the previous version of the CIE, absolute values are shown for bias-corrected climate indicators (level 1). In the updated version of the CIE, additional indicators were calculated using bias-corrected climate data. These serve as proxy indicators for estimating risks from extreme weather events and related economic damages. Examples include the SPEI index; the fire weather index for wildfire risk; and several heat risk indicators, such as the frequency of heat index threshold exceedances and the maximum number of consecutive tropical nights per year. Because these indicators are based on the bias-corrected climate indicators, we have confidence in their absolute values and display them accordingly.

Due to potential biases, the CIE does not provide absolute values for certain indicators. These include impact model - based results such as agricultural yields for different crops, freshwater indicators, as well as heavy precipitation indicators like 5-day extreme precipitation, where we consider relative values more robust and easier to interpret.

### Updates compared to 2024:

- Additional indicators with absolute instead of relative values due to use of bias-corrected climate indicators as shown in the indicator table(new)

## 3 Visualisation

The visualisation features of the CIE provide users with the following capabilities:

- Show time series and maps of indicators for all scenarios in the CIE
- Comparison features:
  - Compare time series between scenarios in a common plot
  - Compare regional results in maps between
    - \* Scenarios
    - \* Warming levels
    - \* Year

The CIE shows one map with each of the compared cases, and to the left of those the difference of values between the two maps.

*Note that absolute value indicator comparisons show differences in absolute values, while comparisons between relative value indicators are shown as percentage point differences.*

For a practical introduction to the CIE, please refer to the updated user guide, which uses illustrative use cases to explain central concepts.

## 4 References

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## 5 Glossary

**Quick Navigation:** B | C | E | G | H | I | M | N | R | S | U

### B

**Bias Adjustment (Bias Correction)** A statistical process that corrects systematic errors (biases) in climate model outputs to better match observations over a reference period. In ISIMIP3b, bias adjustment uses observational reference data (WFDE5/W5E5) to align model simulations with observed climate conditions. See also: ISIMIP3b Bias Adjustment Fact Sheet.

**Related concepts:** - Quantile mapping: A bias adjustment technique that aligns the distribution of model data with observations - Downscaling: Refining coarse-resolution model data to higher spatial resolutions

### C

**CMIP6 (Coupled Model Intercomparison Project Phase 6)** The sixth phase of an international collaborative effort to improve climate models through systematic comparison. CMIP6 provides standardized climate model outputs used as input for impact models like ISIMIP. Includes Earth System Models (ESMs) from leading climate research institutions worldwide.

**External resources:** CMIP6 Overview, ESGF Data Portal

**Climate Sensitivity** The long-term global temperature response to a doubling of atmospheric CO<sub>2</sub> levels, typically expressed as degrees Celsius. A key measure of climate system responsiveness. The IPCC AR6 best estimate is 3°C, with a likely range of 2.5 - 4°C. Higher climate sensitivity implies stronger warming from the same emissions.

### E

**Earth System Model (ESM)** A comprehensive computer model that simulates interactions between atmosphere, ocean, land surface, and ice systems. ESMs simulate physical climate processes and provide projections of future climate under different emission scenarios.

**Emissions Scenario** A plausible pathway of future greenhouse gas emissions based on assumptions about population, economic growth, energy use, and climate policies. Examples include SSPs (Shared Socioeconomic Pathways) and historical RCPs (Representative Concentration Pathways).

**External resources:** Shared Socioeconomic Pathways (SSPs)

**Ensemble** A collection of multiple model runs or simulations (often 5 - 600 members) that explores the range of plausible outcomes given inherent uncertainties in model parameters and initial conditions.

**Equilibrium Climate Sensitivity (ECS)** The steady-state global temperature increase following a doubling of atmospheric CO<sub>2</sub> concentrations, accounting for all climate system feedbacks.

## G

**Global Mean Temperature (GMT)** The average surface air temperature of Earth calculated across all oceans and land areas. A key metric for describing global warming levels (e.g., 1.5°C, 2°C).

**Gridded Data** Climate and impact data organized on a regular spatial grid at specified resolution (e.g., 0.5° E 0.5°, equivalent to ~50 km at the equator). Each grid cell contains values for that geographic location.

## H

**Heat Index (HI)** Originally developed by the U.S. National Weather Service (NWS) as a heat-stress warning tool, the Heat Index is based on Steadman's model of human thermoregulation (Steadman, 1979; Steadman, 1984, which describes heat exchange between the human body and the environment in a single quantitative value that can be classified into heat-stress categories defined by the NWS ranging from 'caution' to 'extreme danger' (Anderson et al., 2013).

**Related concepts:** - Wet-bulb temperature: A measure of combined heat and humidity that affects human comfort and safety - Heat stress: Physiological strain from environmental heat exposure - Apparent temperature: An index combining temperature, humidity, and sometimes wind and radiation

## I

**Inter-Sectoral Impact Model Intercomparison Project (ISIMIP)** An international initiative coordinating climate impact modeling across sectors (agriculture, water, fisheries, health, forests). ISIMIP3b is the third phase, providing standardized outputs from 100+ global impact models.

Phase 3b of ISIMIP, featuring climate input data from CMIP6 and impact model outputs at 0.5° spatial resolution, is used as the primary data source for CIE 2025 indicators.

**External resources:** ISIMIP Official Website, ISIMIP3b Project Page, ISIMIP Data Portal

## M

**MAGICC7 (Model for the Assessment of Greenhouse-gas Induced Climate Change, version 7)** A simple climate model (SCM) that translates emissions scenarios into Global Mean Temperature projections. Used in CIE to generate ensemble GMT trajectories incorporating climate sensitivity uncertainty.

**External resources:** MAGICC Model Documentation

**Model Agreement** The degree of consensus among multiple climate or impact models on projected changes for a given region and variable. Quantifies robustness of projections.

**N**

**Natural Variability** Inherent fluctuations in climate and weather systems due to internal atmospheric/oceanic dynamics, independent of external forcing. Introduces uncertainty in impact projections.

**R**

**RIME-X (Rapid Impact Model Emulator)** A novel probabilistic mapping method (Schwind et al., 2025 that projects GMT trajectories to local impact indicators while explicitly accounting for all uncertainty sources (parameter, model, and climate uncertainty).

**Regional Temperature Response** The projected change in local/regional temperature for a given change in global mean temperature. Varies spatially due to climate phenomena (e.g., polar amplification, land-sea contrasts).

**S**

**Scenario (Climate/Emissions)** A plausible pathway of future greenhouse gas emissions and socio-economic conditions used to drive climate models.

**Statistical Downscaling** A process that refines coarse-resolution model data (e.g., 2ř) to higher spatial resolution (e.g., 0.5ř) using statistical relationships or observational reference data.

**U**

**Uncertainty** Imperfect knowledge about future climate and impacts, arising from multiple sources: parameter uncertainty (model calibration), model uncertainty (different model structures), and climate uncertainty (natural variability).

**Uncertainty Range (Ensemble Spread)** The spread of outcomes across an ensemble of model runs, quantifying the plausible range of projected changes.