Computing extreme indices for GWLs projections

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from The IPCC Sixth Assessment Report (WG1- *Chapter 1* and *Annex VI)* :

Definition of Climatic-impact drivers (CIDs)

Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. In contrast to the term "hazards", it provides a more value-neutral characterization of climatic changes that may be relevant for understanding potential impacts, without pre-judging from The IPCC Sixth Assessment Report (WG1- *Chapter 1* and *Annex VI)* :

Definition of Climatic-impact drivers (CIDs)

'Extremes' are a category of CID, corresponding to unusual events with respect to the range of observed values of the variable.

- **Climatic impact-drivers may not be related only to extremes;**

'Climatic impact-driver indices' are numerically computable indices using one or a combination of climate variables designed to measure the intensity of the climatic impact-driver, or the probability of exceedance of a threshold.

- **Indices are, in principle, computable from observations, reanalyses or model simulations**, although it is important to consider scale in comparing across datasets. For example, an extreme precipitation event has a lower magnitude across a large grid cell than it would at a single station within that grid cell.

A complete set of extreme indices has been identified in the *IPCC Sixth Assessment Report:*

Table AVI.1 | Table listing extreme indices used in Chapter 11.

Extreme	Label	Index Name	Units	Variable
Temperature	TXx	Monthly maximum value of daily maximum temperature	°C	Maximum temperature
	TXn	Monthly minimum value of daily maximum temperature	°C	Maximum temperature
	TNn	Monthly minimum value of daily minimum temperature	°C	Minimum temperature
	TNx	Monthly maximum value of daily minimum temperature	°C	Minimum temperature
	TX90p	Percentage of days when daily maximum temperature is greater than the 90th percentile	%	Maximum temperature
	TX10p	Percentage of days when daily maximum temperature is less than the 10th percentile	%	Maximum temperature
	TN90p	Percentage of days when daily minimum temperature is greater than the 90th percentile	%	Minimum temperature
	TN10p	Percentage of days when daily minimum temperature is less than the 10th percentile	%	Minimum temperature
	ID	Number of icing days: annual count of days when TX (daily maximum temperature) <0°C	Days	Maximum temperature
	FD	Number of frost days: annual count of days when TN (daily minimum temperature) <0°C	Days	Minimum temperature
	WSDI	Warm spell duration index: annual count of days with at least six consecutive days when TX >90th percentile	Days	Maximum temperature
	CSDI	Cold spell duration index: annual count of days with at least six consecutive days when TN <10th percentile	Days	Minimum temperature
	SU	Number of summer days: annual count of days when TX (daily maximum temperature) >25°C	Days	Maximum temperature
	TR	Number of tropical nights: annual count of days when TN (daily minimum temperature) >20°C	Days	Minimum temperature
	DTR	Daily temperature range: monthly mean difference between TX and TN	°C	Maximum and minimum temperature
	GSL	Growing season length: annual (1 Jan to 31 Dec in Northern Hemisphere (NH), 1 July to 30 June in Southern Hemisphere (SH)) count between first span of at least six days with daily mean temperature TG >5°C and first span after July 1 (Jan 1 in SH) of six days with TG <5°C	Days	Mean temperature
	20TXx	One-in-20 year return value of monthly maximum value of daily maximum temperature	°C	Maximum temperature
	20TXn	One-in-20 year return value of monthly minimum value of daily maximum temperature	°C	Maximum temperature
	20TNn	One-in-20 year return value of monthly minimum value of daily minimum temperature	°C	Minimum temperature
	20TNx	One-in-20 year return value of monthly maximum value of daily minimum temperature	°C	Minimum temperature
Precipitation	Rx1day	Maximum one-day precipitation	mm	Precipitation
	Rx5day	Maximum five-day precipitation	mm	Precipitation
	R5mm	Annual count of days when precipitation is greater than or equal to 5 mm	Days	Precipitation
	R10mm	Annual count of days when precipitation is greater than or equal to 10 mm	Days	Precipitation
	R20mm	Annual count of days when precipitation is greater than or equal to 20 mm	Days	Precipitation
	R50mm	Annual count of days when precipitation is greater than or equal to 50 mm	Days	Precipitation
	CDD	Maximum number of consecutive days with less than 1 mm of precipitation per day	Days	Precipitation
	CWD	Maximum number of consecutive days with more than or equal to 1 mm of precipitation per day	Days	Precipitation
	R95p	Annual total precipitation when the daily precipitation exceeds the 95th percentile of the wet-day (>1 mm) precipitation	mm	Precipitation
	R99p	Annual precipitation amount when the daily precipitation exceeds the 99th percentile of the wet-day precipitation	mm	Precipitation
	SDII	Simple precipitation intensity index	mm day^{-1}	Precipitation
	20Rx1day	One-in-20 year return value of maximum one-day precipitation	mm day^{-1}	Precipitation
	20Rx5day	One-in-20 year return value of maximum five-day precipitation	mm day^{-1}	Precipitation
Drought	SPI	Standardized precipitation index	Months	Precipitation
	EDDI	Potential evaporation, evaporative demand drought index	Months	Evaporation
	SMA	Soil moisture anomalies	Months	Soil moisture
	SSMI	Standardized soil moisture index	Months	Soil moisture
	SRI	Standardized runoff index	Months	Streamflow
	SSI	Standardized streamflow index	Months	Streamflow
	PDSI	Palmer drought severity index	Months	Precipitation, evaporation
	SPEI	Standardized precipitation evapotranspiration index	Months	Precipitation, evaporation, temperature

IPCC, 2021: Annex VI: Climatic Impact-driver and Extreme Indices [Gutiérrez J.M., R. Ranasinghe, A.C. Ruane, R. Vautard (eds.)]. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 2205–2214, doi:10.1017/9781009157896.020.

CID categories are identified on the basis of relevance for risks and impacts and available literature. They are classified into seven types: heat and cold, wet and dry, wind, snow and ice, coastal, open ocean, and other

Table AVI.2 | Regional CID indices table and relevant references.

CID Category	Climatic Impact-driver (from Table 12.1) and Potential Affected Sectors	Index	Required ECVs	Way to Calculate	Bias Adjustment	References
Heat	Change in cooling demand for energy demand and building consumption	Cooling degree days above 22°C	Tas, tasmin, tasmax	From projections	Yes	Spinoni et al. (2015, 2018)
	Heat, with thresholds important for agriculture	Number of days with Tmax >35°C or 40°C (TX35, TX40)	Tasmax	From projections	Yes	Hatfield and Prueger (2015); Hatfield et al., (2015); Grotjahn (2021)
	Heat stress index combining humidity used in occupational and industrial health	NOAA heat index (HI): number of days above 41°C threshold	Tasmax, huss, ps	From projections	Yes	Burkart et al. (2011); Lin et al. (2012); Kent et al. (2014)
Cold	Heating degree day for energy consumption	Heating degree days below 15.5°C	Tas, tasmin, tasmax	From projections	Yes	Spinoni et al. (2015, 2018)
	Frost	Number of frost days below 0°C (FD)	Tasmin	From projections	Yes	Barlow et al. (2015); Rawlins et al. (2016)
Wet	River flooding	Flood index (FI)	srroff/mrro	From projections and simplified routing model	No	Forzieri et al. (2016); Alfieri et al. (2017)
Drought	Aridity	Soil moisture (SM)	mrso	From projections	No	Cook et al. (2020)
	Droughts	Standardized Precipitation Index accumulated over 6 months (SPI-6)	Pr	From projections	No	Naumann et al. (2018)
Wind & storm	Mean wind speed	Annual mean wind speed	sfcWind	From projections	No	Karnauskas et al. (2018); Li et al. (2018)
Snow/ice	Snow season length	Number of days with snow water equivalent >100 mm (SWE100) over the snow season (Nov–Mar for NH)	Snw	From projections	No	Damm et al. (2017); Wobus et al. (2017)
Coastal	Extreme sea level (ETWL) inducing storm surges	1-in-100-year return period level (ETWL)		Data from authors	No	Vousdoukas et al. (2018)
	Coastal erosion	Shoreline retreat by mid- and end of century		Data from authors	No	Vousdoukas et al. (2020)

IPCC, 2021: Annex VI: Climatic Impact-driver and Extreme Indices [Gutiérrez J.M., R. Ranasinghe, A.C. Ruane, R. Vautard (eds.)]. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 2205–2214, doi:10.1017/9781009157896.020.

IMPETUS 4CHANGE

WP4 – Hazard indices for Europe

Space for another logo
Remove white bloc if not needed

This project has received funding from the European Union's

WP4 Objectives:

The aim is to define a stakeholder-relevant set of extreme and hazard indicators for Europe, assessing locally-relevant tipping points and thresholds under different scenarios.

Instead of the classic Time of Emergence, a new approach based on Global Warming Levels (GWLs) has been applied, in order to overcome the dependency from the emissions pathways and the single models.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081555

The method: from *ToE to GToE*

- *Time of Emergence (ToE)* is an indicator of the magnitude of the climate change signal relative to the background variability.
- There is no single metric for *ToE*. It depends on user-driven choices of variables, space and time scales, the baseline relative to which changes are measured, and the threshold at which emergence is defined (Kirtman et al. 2013).
- For OBSERVATIONS, the *noise* is the interannual variability;
- when dealing with an ENSEMBLE OF MODELS, the inter-models' spread should be considered too;
- moreover, GCMs can refer to the pre-industrial period as the reference; RCMs should consider a more recent period since there is no avaliablity of data before 1970.
- >> TOE assessment is affected by methodological choices!

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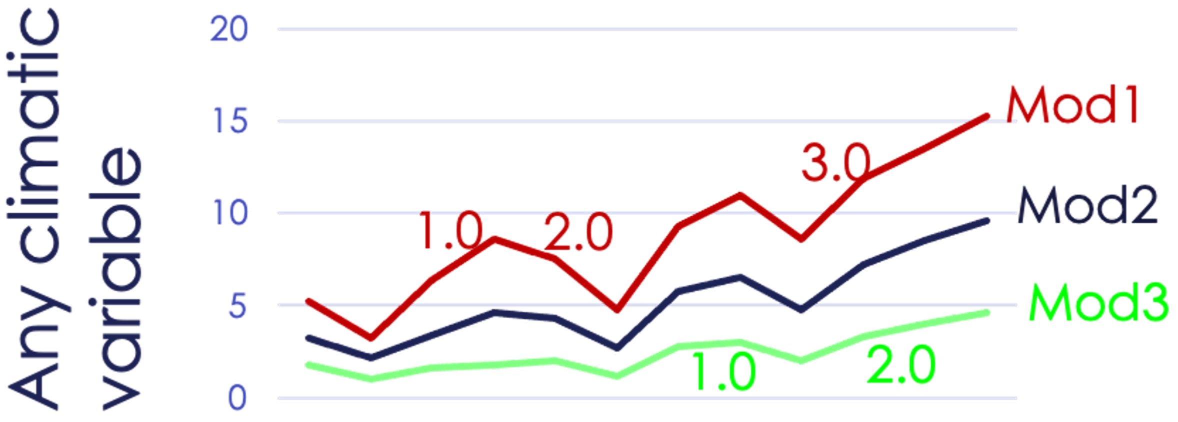
The method: from *ToE to GToE*

- The ***Global Temperature of Emergence (GToE)*** is an alternative to the *ToE* concept: by replacing time with global mean temperature, it makes no difference among models and emission pathways and it is more directly aligned with climate policy targets!



The GToE is thus defined on the basis of thresholds of temperature, the **Global Warming Levels (GWLs)**, expressed as changes in surface global temperature relative to the period 1850-1900.

The approach based on **Global Warming Levels (GWLs)** is applied, in order to overcome the dependency from the emissions pathways and the single models.

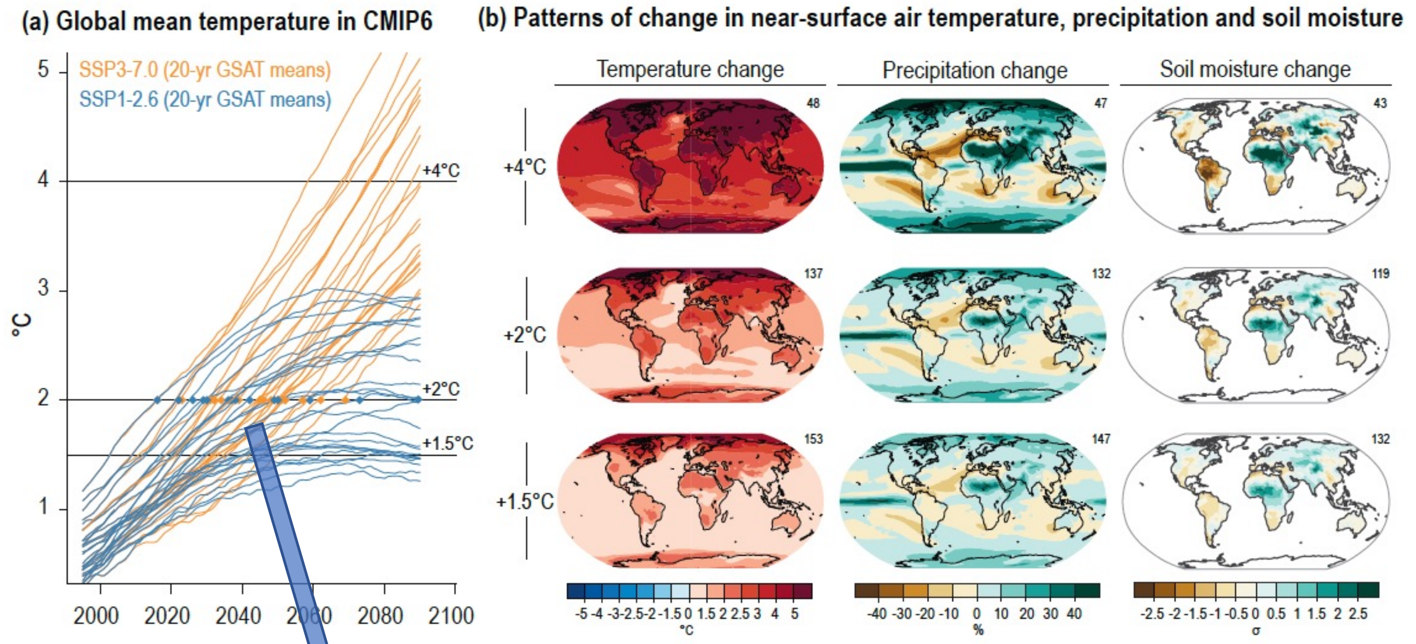
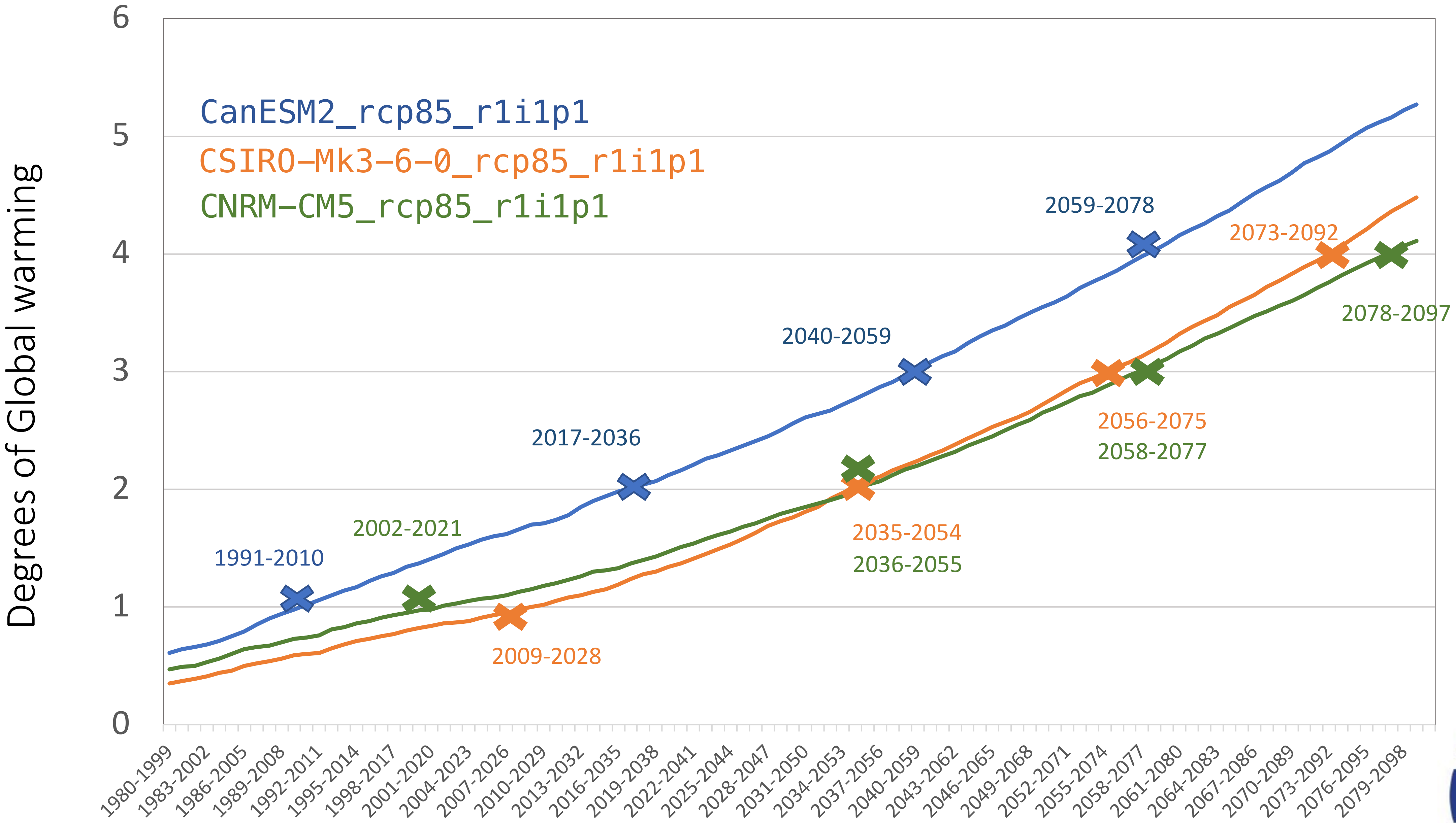


Figure TS.5 | Scenarios, global warming levels, and patterns of change. *The intent of this figure is to show how scenarios are linked to global warming levels (GWLs) and to provide examples of the evolution of patterns of change with global warming levels.* **(a)** Illustrative example of GWLs defined as global surface temperature response to anthropogenic emissions in unconstrained Coupled Model Intercomparison Project Phase 6 (CMIP6) simulations, for two illustrative scenarios (SSP1-2.6 and SSP3-7.0). The time when a given simulation reaches a GWL, for example, +2°C, relative to 1850–1900 is taken as the time when the central year of a 20-year running mean first reaches that level of warming. See the dots for +2°C, and how not all simulations reach all levels of warming. The assessment of the timing when a GWL is reached takes into account additional lines of evidence and is discussed in Cross-Section Box TS.1. **(b)** Multi-model, multi-simulation average response patterns of change in near-surface air temperature, precipitation (expressed as percentage change) and soil moisture (expressed in standard deviations of interannual variability) for three GWLs. The number to the top right of the panels shows the number of model simulations averaged across including all models that reach the corresponding GWL in any of the five Shared Socio-economic Pathways (SSPs). See Section TS.2 for discussion. {Cross-Chapter Box 11.1}

The climate response pattern for the 20-year period around when individual simulations reach a given GWL are averaged across all models and scenarios that reach that GWL.

The time when a given simulation reaches a GWL, for example, +2C, relative to 1850–1900 is taken as the time when the central year of a 20-year running mean first reaches that level of warming. See the dots for +2C, and how not all simulations reach all levels of warming.

An example of GWLs calculation:



Selection of hazard indicators

Hazard indices	Description/Calculation	Critical sector of exposure	References	Demonstrator(s)
TNnTrop Annual	Number of tropical nights. Minimum night-time temperature > 20 °C Annual frequency, and the maximum and average period length for periods of 3 or more days in length	Heatwaves, Human health,		Barcelona, Bergen, Prague
TNnEqua Annual	Number of equatorial nights. Minimum night-time temperature > 25 °C Annual frequency, and the maximum and average period length for periods of 3 or more days in length	Heatwaves, Human health,		Barcelona, Bergen, Prague
Tx25 Annual	Number of Summer Days with maximum daily temperature above 25 degrees Annual frequency, and the maximum and average period length for periods of 3 or more days in length	Human health, infrastructure, ecosystems, agriculture	Deryng et al. 2014 Petitti et al. 2016	Paris, Prague, Barcelona
HW Annual	Heat wave as 3 consecutive days with TX above the daily threshold (p90 of TXd over ± 15 days) for the reference period 1981-2010. Annual frequency, and the maximum and average period length.	Human health, ecosystems	Russo et al., 2014; 2015	Barcelona, Prague, Paris
HEvent Annual	Heat event as 1-2 consecutive days with TX above the daily threshold (p90 of TXd over ± 15 days) for the reference period 1981-2010.	Human health, ecosystems	Russo et al., 2014; 2015	Barcelona, Prague
EHF (Excess Heat Factor)	Quantifies heat wave severity/intensity based on three-day-averaged daily mean temperature (DMT). $EHI_{sig} = (T_i + T_{i+1} + T_{i+2})/3 -$ $EHI_{accl} = (T_i + T_{i+1} + T_{i+2})/3 - (T_{i-1} + \ldots + T$ $EHF = EHI_{sig} \times \max(1, EH$	Heatwaves, Human Health	Nairn & Fawcett (2014)	Barcelona, Prague, Paris
NOAA Heat index (HI)	The 'Heat Index' is a measure of how the hot weather "feels" to the body. The index uses relative humidity and air temperature to produce the "apparent temperature" or the temperature the body feels" $HI = \begin{cases} HI_1 + HI_{A1}, & \text{if RH} < 13\,\% \text{ and } 80\,°F < T_F < 11 \\ HI_1 + HI_{A2}, & \text{if RH} > 85\,\% \text{ and } 80\,°F < T_F < 87 \\ HI_1, & \text{otherwise} \end{cases}$ with: $HI_1 = c_0 + c_1 \cdot T_F + c_2 \cdot RH + c_3 \cdot T_F \cdot RH + c_4 \cdot T_F^2 + c_5 \cdot$ $+ c_8 \cdot T_F^2 \cdot RH^2$ $HI_{A1} = (13 - RH)/4 \cdot \sqrt{(17 - \lvert T_F - 95\,°F \rvert)/17}$ $HI_{A2} = (RH - 85)/10 \cdot (87\,°F - T_F)/5$ $c_0 = -42.379\,°F, c_1 = 2.04901523, c_2 = 10.14333127\,°F, c_3$ $c_4 = -0.00683783\,°F^{-1}, c_5 = -0.05481717\,°F, c_6 = 0.0012$ $c_8 = -0.00000199\,°F^{-1}$ If HI < 80 °F, the following equation is used: $HI = 0.5 \cdot (T_F + 61\,°F + 1.2 \cdot (T_F - 68\,°F) + 0.094\,°F \cdot RH$ The calculated HI is converted into °C.	Human health, ecosystems	Annex VI: Climatic Impact-driver and Extreme Indices (IPCC Sixth Assessment Report – WG1) ; Burkart et al. (2011); Lin et al. (2012); Kent et al. (2014), Lu and Romps (2022)	Barcelona, Paris, Prague
CDD Annual	Given a threshold Tb=22°C: $CDD_i = \begin{cases} 0 \\ \frac{T_X - T_b}{4} \\ \frac{T_X - T_b}{2} - \frac{T_b - T_N}{4} \\ T_M - T_b \end{cases}$ if Then: $CDD = \sum^{365} CDD_i$	Energy consumption for cooling	Spinoni et al. 2015 https://ec.europa.eu/eurostat/cache/metadata/en/nrg_chdd_esms.htm	Barcelona, Paris, Prague, Bergen, Newcastle, Hamburg
HDD Annual	Given a threshold Tb=15°C: $HDD_i = \begin{cases} T_b - T_M \\ \frac{T_b - T_N}{2} - \frac{T_X - T_b}{4} \\ \frac{T_b - T_N}{4} \\ 0 \end{cases}$ if Then: $HDD = \sum_{i=1}^{365} HDD_i$	Energy demand for heating	Spinoni et al. 2015	Paris, Prague, Barcelona, Bergen, Newcastle, Hamburg
PrRnn	nn year return value of daily precipitation, e.g., nn= 2, 5, 10, 20, 50, 100, 200 years	Pluvial flooding, ecosystems and crop growth		Bergen, Prague
RX1day Annual	Maximum 1 day precipitation	Pluvial flooding, ecosystems and crop growth		Bergen, Newcastle, Barcelona, Prague
CWD Annual	**CWD**: consecutive wet day /maximum length of wet spell (RR ≥ 1 mm)	Water resources management, Tourists, Flooding, Ecosystems	Climate Indices and Analysis for Sectoral Application, WMO: https://indico.ictp.it/event/a10167/session/16/contribution/12/material/0/0.pdf	Bergen, Prague
Rnnmm Annual	**Rnnmm**: count of days where RR ≥ user-defined threshold in mm. For example, precipitation based on percentile value.	Water resources management, Tourists, Flooding, Ecosystems	Climate Indices and Analysis for Sectoral Application, WMO: https://indico.ictp.it/event/a10167/session/16/contribution/12/material/0/0.pdf	Bergen, Prague
SPI 6 months	Standardised Precipitation Index		WMO (2012)	Barcelona
NDD	Number, average length, and maximum length of dry spells. A dry spell is a period during which the daily precipitation is below a threshold of 1 mm.	Heatwaves, Droughts, Eco systems, Crop growth	Cindric et al. (2010), Manning et al., (2023)	Barcelona, Bergen, Prague, Paris
DF Decadal	Drought frequency based on a 6-month SPI	Ecosystems and agriculture	Spinoni et al. 2014	Barcelona,Prague
Fire Weather Index (FWI)	Fire Weather Index/ a meteorologically based index used worldwide to estimate fire danger. It is calculated using 24-h accumulated precipitation, instantaneous wind speed, relative humidity and daily max temperature.	Human health, ecosystems, infrastructure	Bedia et al., (2013), Bedia et al., (2018) Alternative is Fire Occurrence Probability Index (FOPI) which also considers fuel. Giuseppe et al 2023	Barcelona, Bergen, Prague
RxHhr	Simple monthly maxima of H-hour (1-hour and 3-hour) precipitation series (using a sliding window to identify maxima when H > 1)	Flooding	Pritchard, D.M.W., Lewis, E., Blenkinsop, S., Patino Velasquez, L., Whitford, A., Fowler, H.J. GSDR-I: An Observation-Based Dataset of Global Sub-Daily Precipitation Indices. Scientific Data, in press.	Newcastle, Bergen
RHhrTmm	Count of hours with greater than 30 or 50 mm thresholds (T)	Flooding	Pritchard, D.M.W., Lewis, E., Blenkinsop, S., Patino Velasquez, L., Whitford, A., Fowler, H.J. GSDR-I: An Observation-Based Dataset of Global Sub-Daily Precipitation Indices. Scientific Data, in press.	Newcastle, Bergen

Indices for specific Demonstrators only:

Hazard indices	Description/Calculation	Critical sector of exposure	References	Demonstrator(s)
Q100 Annual	(1) Daily discharge for each climate experiment are produced for a 130 year period (e.g. 1970-2100) (2) Annual maximum river discharge were selected and a Gumbel distribution was fitted on time slices of 30 years From the distribution, the peak corresponding to the 100 year return period is calculated	Flooding, infrastructure	Alfieri et al. 2015a, b Forzieri et al. 2016a, b Already calculated by ICTP – Extract for individual demonstrator cities	Bergen, Prague, Barcelona
Météo France Index	A heat wave occurs when the mean temperature is greater than 25.3 °C and at least > 23,4 °C for 3 consecutive days and always above 22,4 °C	Human health, ecosystems	https://meteofrance.com/	Paris ONLY
H-ASI	Stagnant days defined as days on which three conditions are met simultaneously: Daily precipitation accumulation < 1mm/day, Daily mean (10m) near-surface wind speed < 3.2m/s, Daily mean 500hPa wind speed < 13m/s.	Air quality	Horton, D. E., Skinner, C. B., Singh, D., & Di enbaugh, N. S. (2014). Occurrence and persistence of future atmospheric stagnation events. Nature climate change, 4(8), 698-703.	Prague ONLY
Meteo Cat Number of heat events and heat waves	MeteoCat definition of temperature threshold is 98th percentile compared to last decade of June-August average max temperatures (calculated for June-August 2012-2021 period). A heatwave is a period of 3 or more consecutive days above this threshold. A heat event is 1 - 2 consecutive days above this level.	Heatwaves, Human health		Barcelona ONLY

Hazard Indicators: Definitions

- **TX25**: N. Summer days
- **TN20**: N. Tropical nights
- **RX1DAY**: highest 1-day precip
- **NDD**: N. dry days
- **CDDmax/mean**: consecutive dry days
- **CWDmax**: consecutive wet days
- **HI41**: Heat Index
- **CoolDD & HeatDD**: Cooling and Heating Degree days
- **DF**: Drought Frequency
- **FWI** : Fire weather Index

Hazard Indicators: Definitions

CDD: **Cooling degree days**, a measure of the energy consumption for cooling in hot environments. It is based on the daily mean, maximum and minimum temperature and it is computed as in Spinoni et al. (2015), except that here the sum is cumulated over the whole year (instead of 6 months) so that it applies to both Hemispheres.

Input: daily min. max and mean temperature!

Hazard Indicators: Definitions

$$CDD_i = \begin{cases} 0 \\ \frac{T_X - T_b}{4} \\ \frac{T_X - T_b}{2} - \frac{T_b - T_N}{4} \\ T_M - T_b \end{cases} \quad if \quad \begin{cases} T_X \le T_b \\ T_M \le T_b < T_X \\ T_N \le T_b < T_M \\ T_N \ge T_b \end{cases}$$

Given a threshold Tb=22°C

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Then:

$$CDD = \sum_{i=1}^{365} CDD_i$$

Input: daily min. max and mean temperature!

Hazard Indicators: Definitions

HDD: **Heating Degree Days**: similarly to the CDD, it is the energy demand for heating and it is computed as in Spinoni et al. (2015), but for the whole year.

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Input: daily min. max and mean temperature!

Hazard Indicators: Definitions

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$$HDD_i = \begin{cases} T_b - T_M & \text{if } T_X \le T_b \\ \frac{T_b - T_N}{2} - \frac{T_X - T_b}{4} & \text{if } T_M \le T_b < T_X \\ \frac{T_b - T_N}{4} & \text{if } T_N \le T_b < T_M \\ 0 & \text{if } T_N \ge T_b \end{cases}$$

Given a threshold Tb= 15.5°C

Input: daily min. max and mean temperature!

Then:

$$HDD = \sum_{i=1}^{365} HDD_i$$

Hazard Indicators: Definitions

SPI-6: the Standardized Precipitation Index (for a time window of 6 months): a drought starts in the month when SPI-6 falls below −1 and it ends when SPI-6 returns to positive values for at least two consecutive months, as in Spinoni et al. (2014).

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Drought Frequency (DF): the total number of drought events in a decade

Input: monthly precipitation!

Hazard Indicators: Definitions

Heat Index (HI41- NOAA): it is a widely used measure of apparent temperature that accounts for the effects of humidity using Steadman's model of human thermoregulation.

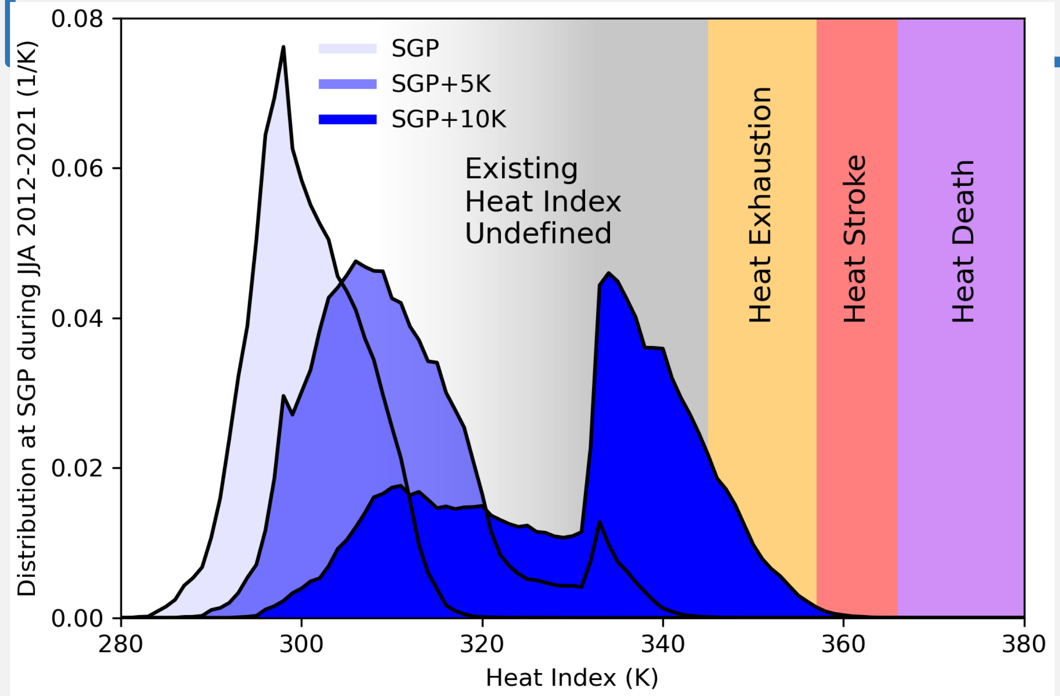
Input:
DAILY Hurs, tasmax;
or:
HOURLY hurs and tas!

It is well-defined for most combinations of high temperature and humidity experienced on Earth in the preindustrial climate, **but global warming** is increasingly generating conditions for which the heat index is undefined!

Hazard Indicators: Definitions

Entended Heat Index (HI41): here, Steadman's thermoregulation model is extended to define the heat index for all combinations of temperature and humidity, allowing for an assessment of Earth's future habitability. (Lu and Romps, 2022)

Input:
DAILY Hurs, tasmax;
or:
HOURLY hurs and tas!



To illustrate the change in the heat index under different warming scenarios, two other distributions are plotted by adding either 5 (blue) or 10 (dark blue) K to the SGP summer-time temperatures while keeping the relative humidities fixed.
The change in the heat index is not a simple translation as the distribution in temperature–humidity space but has a nonlinear response to warming.

Hazard Indicators: Definitions

Entended Heat Index (HI41): here, Steadman's thermoregulation model is extended to define the heat index for all combinations of temperature and humidity, allowing for an assessment of Earth's future habitability. (Lu and Romps, 2022)

Input:
DAILY Hurs, tasmax;
or:
HOURLY hurs and tas!

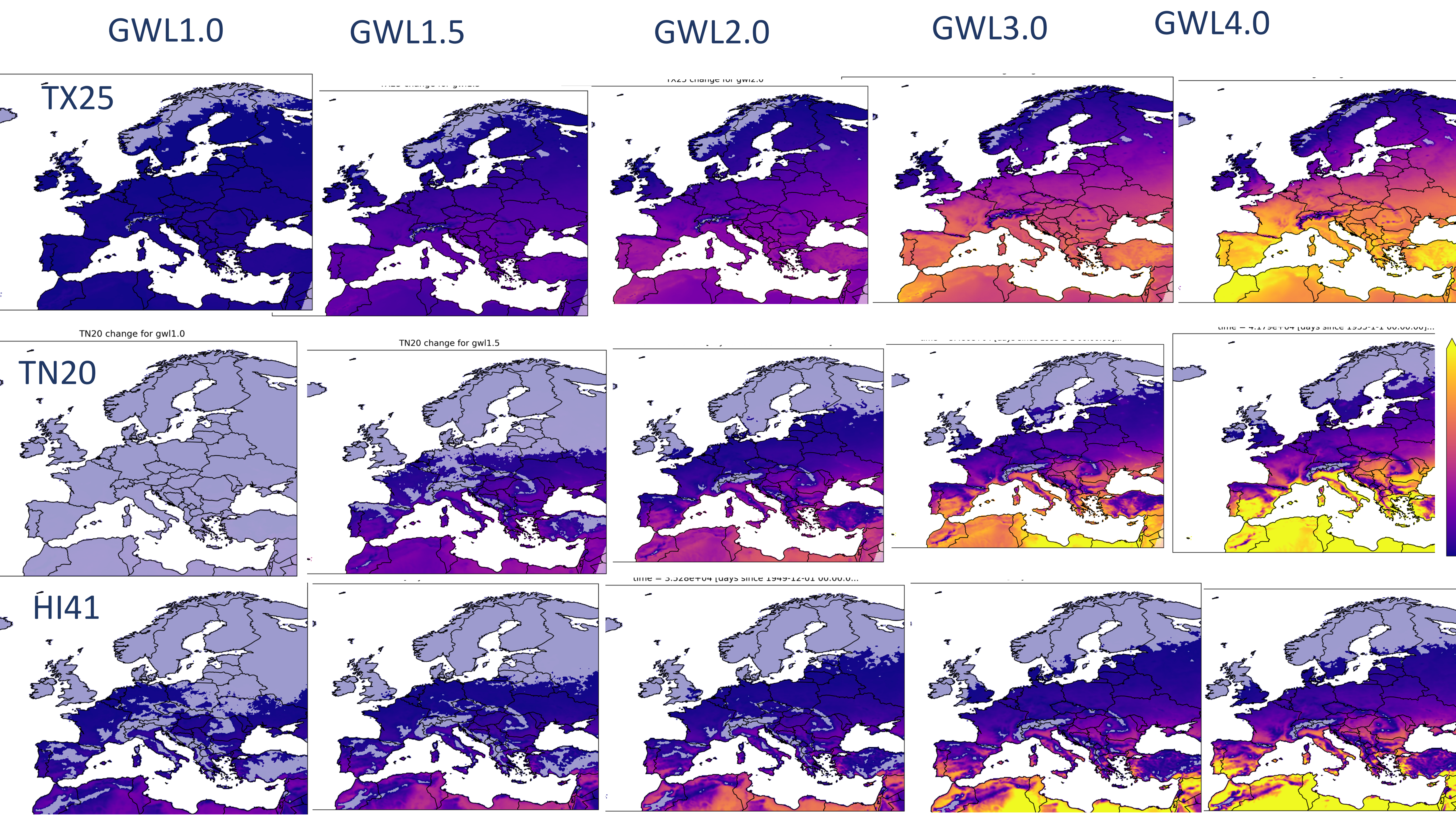
Here you can read on the comparison between the "standard" Heat Index and the "extended" one:

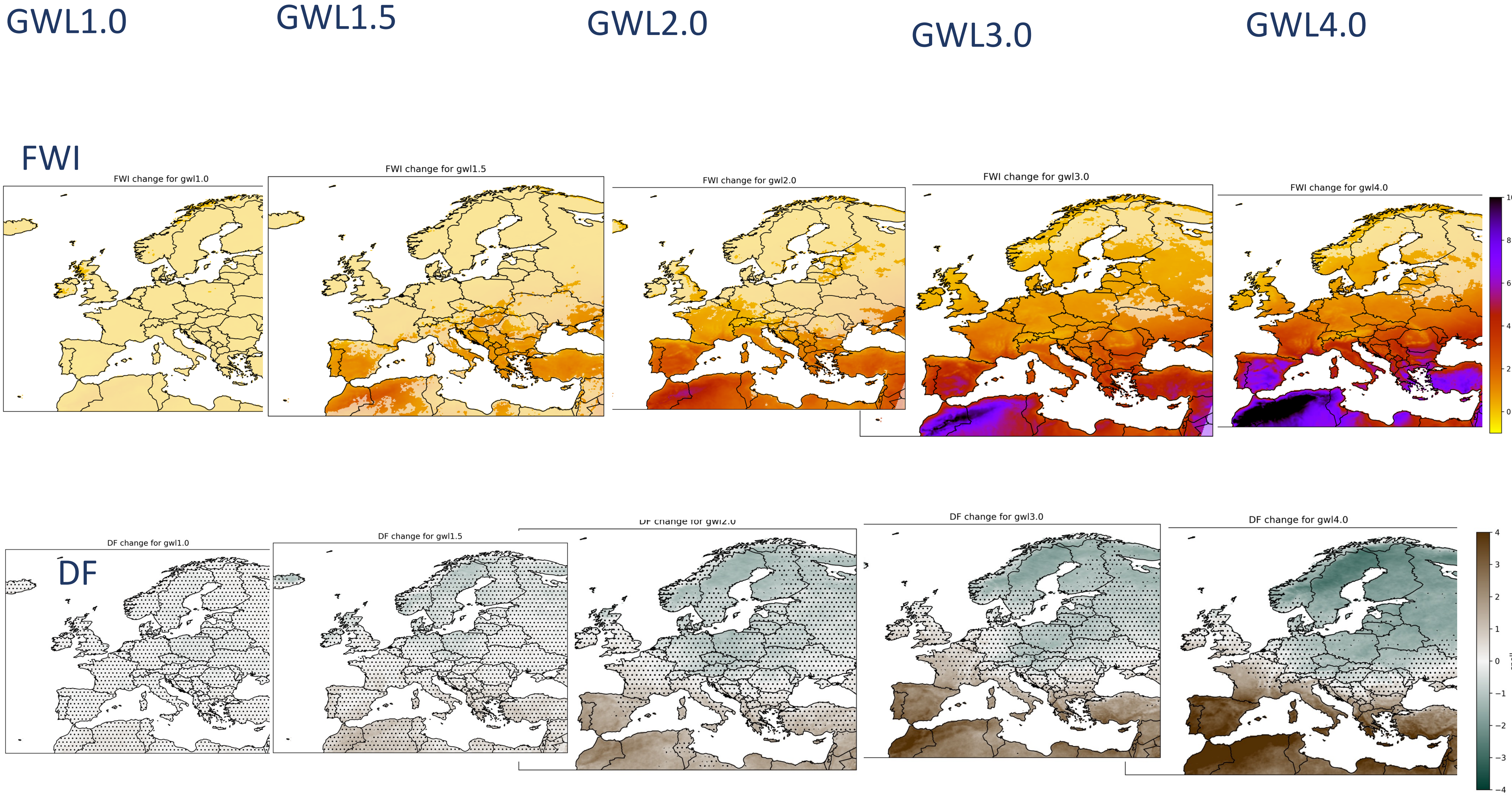
- https://iopscience.iop.org/article/10.1088/1748-9326/ac8945/pdf

Here there are fortran and python scripts to compute the HI:

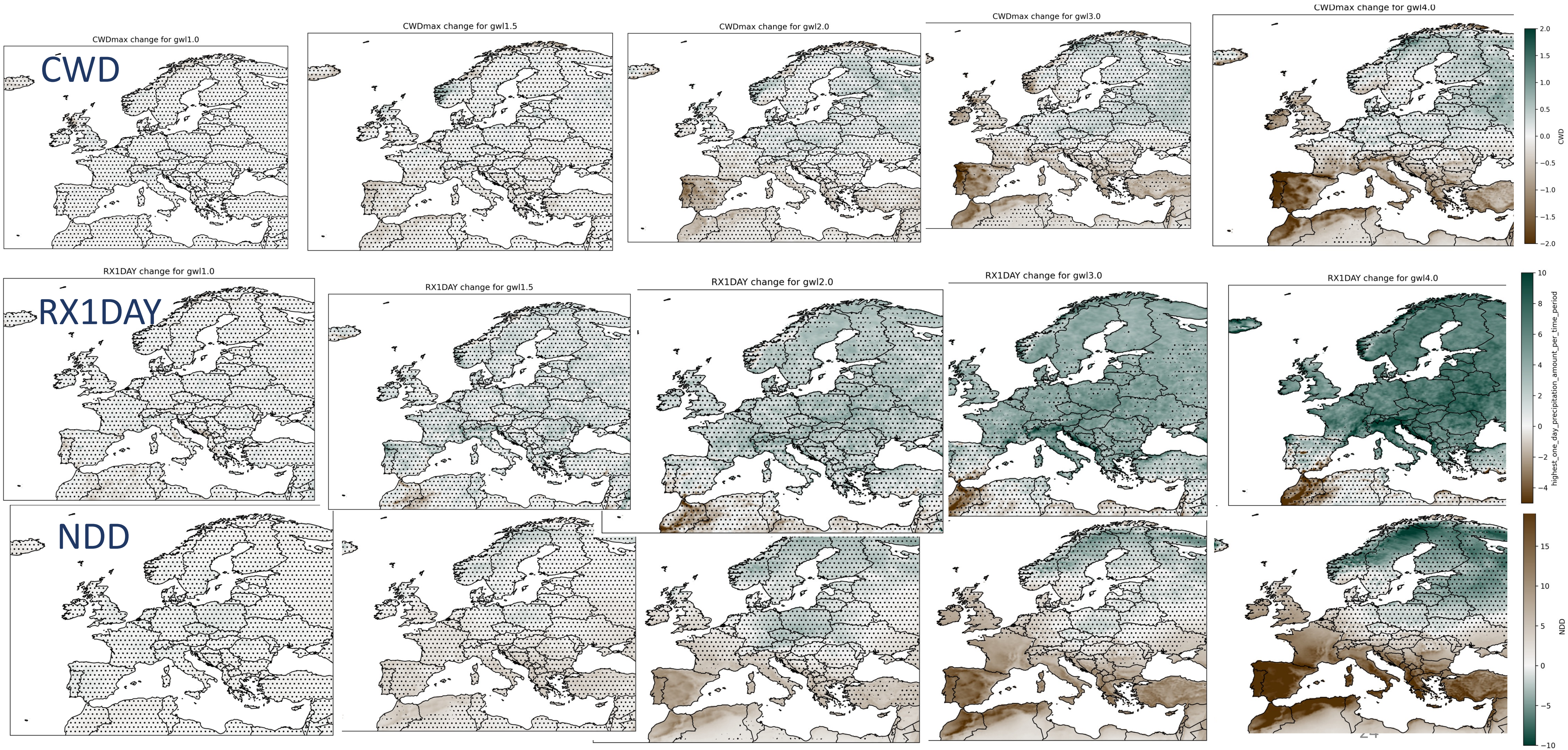
- https://romps.berkeley.edu/papers/pubs-2020-heatindex.html

ICTP

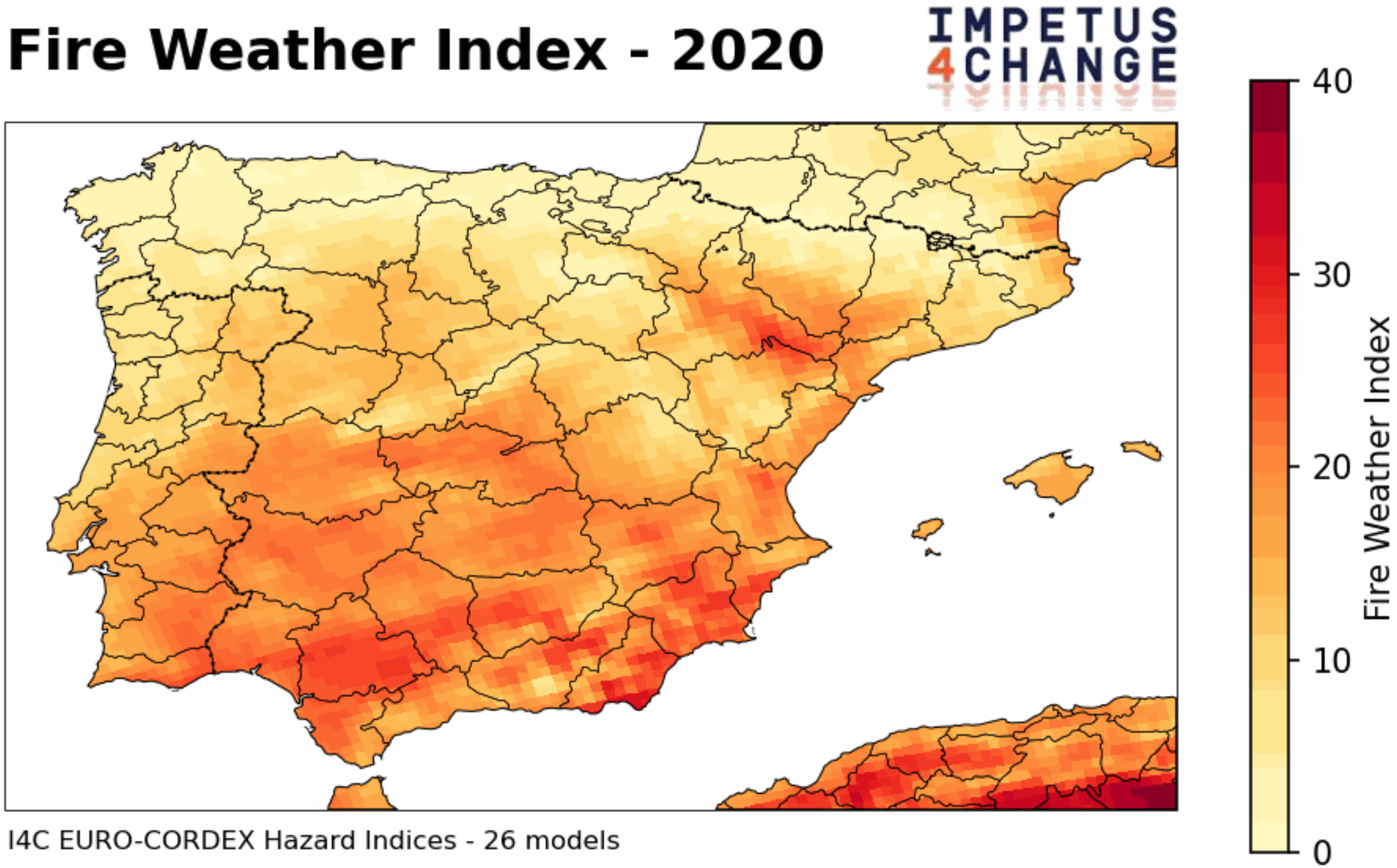

GWL1.0
GWL1.5
GWL2.0
GWL3.0
GWL4.0
TX25
TN20 change for gwl1.0
TN20
TN20 change for gwl1.5
HI41


GWL1.0
GWL1.5
GWL2.0
GWL3.0
GWL4.0
FWI
FWI change for gwl1.0
FWI change for gwl1.5
FWI change for gwl2.0
FWI change for gwl3.0
FWI change for gwl4.0
DF
DF change for gwl1.0
DF change for gwl1.5
DF change for gwl2.0
DF change for gwl3.0
DF change for gwl4.0

GWL1.0 GWL1.5 GWL2.0 GWL3.0 GWL4.0



Fire Weather Index - 2020

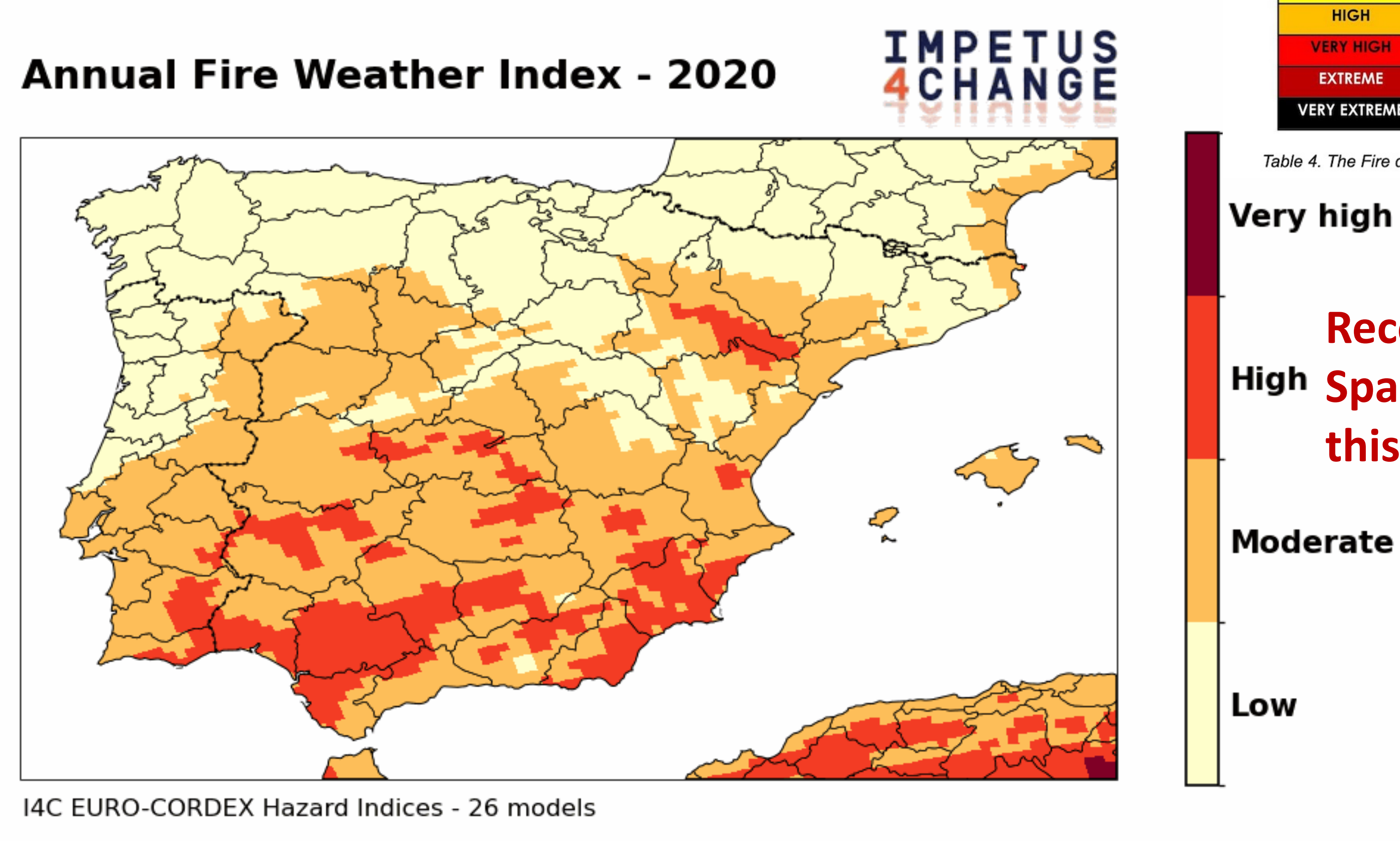


I4C EURO-CORDEX Hazard Indices - 26 models

Input:
DAILY hurs, tasmax, sfwind, precipitation!

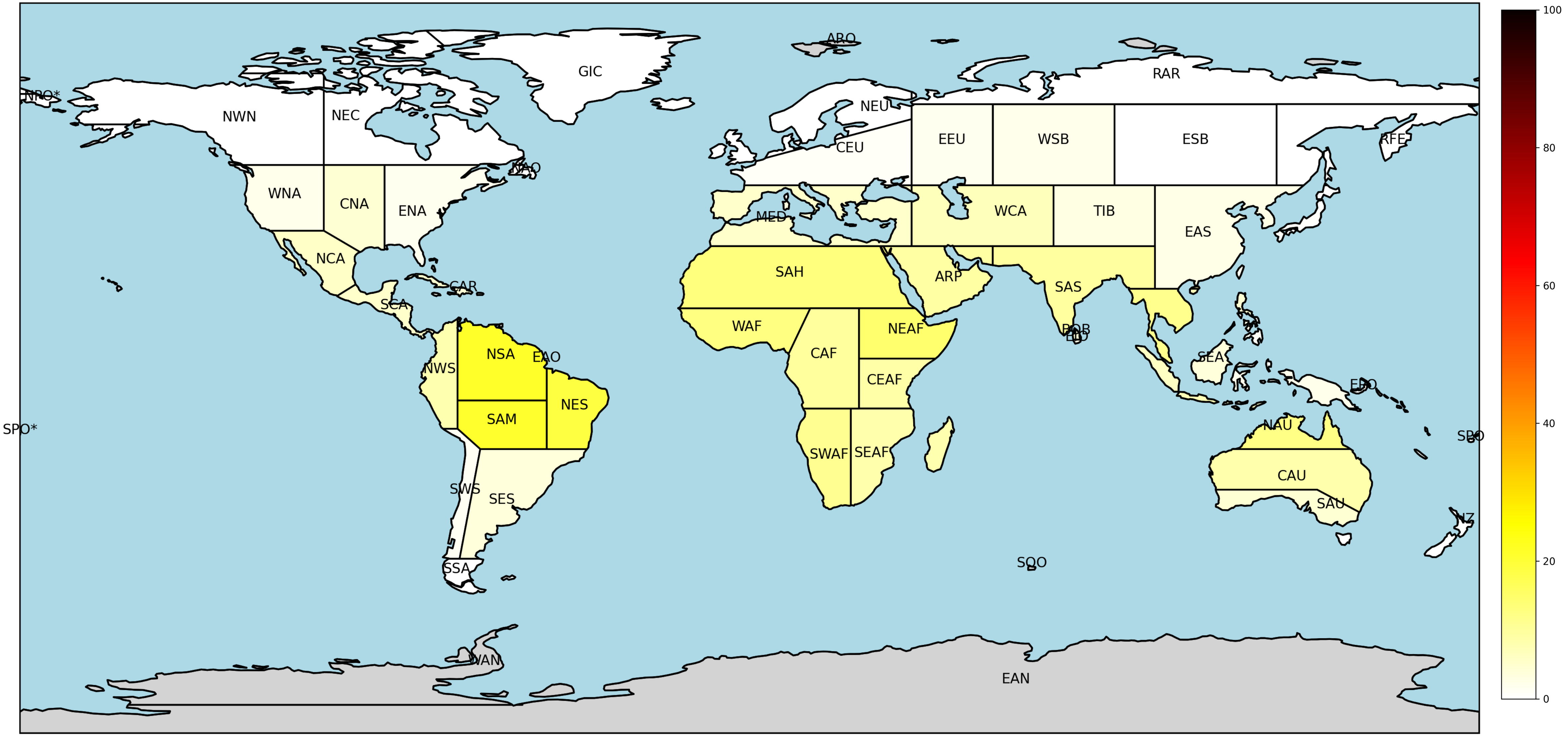
FWI category	FWI values
LOW	0 - 11.2
MODERATE	11.2 -21.3
HIGH	21.3 - 38
VERY HIGH	38 - 50
EXTREME	50 - 70
VERY EXTREME	>=70

Table 4. The Fire danger classes according to EFFIS

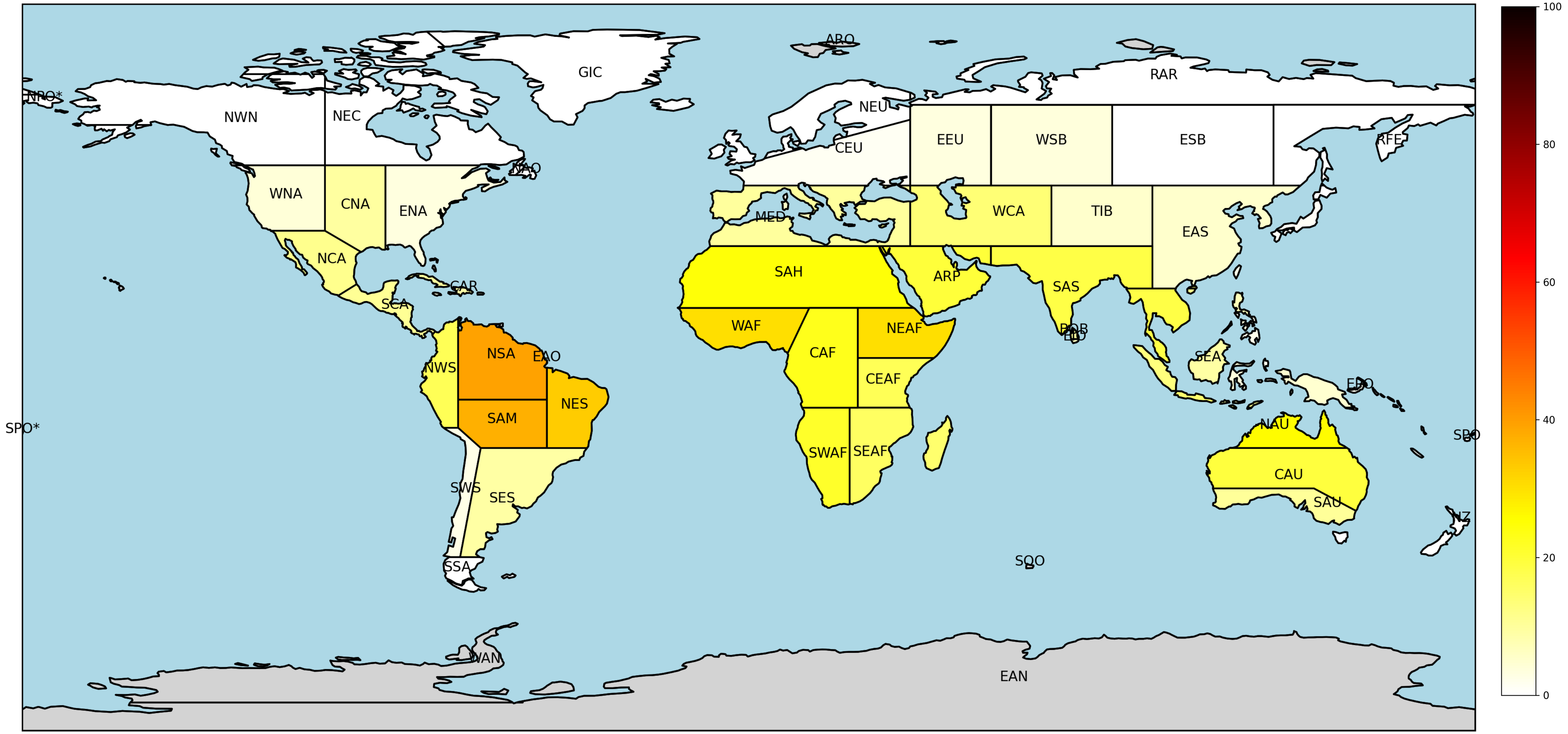


Record wildfires in Spain and Portugal this August!!

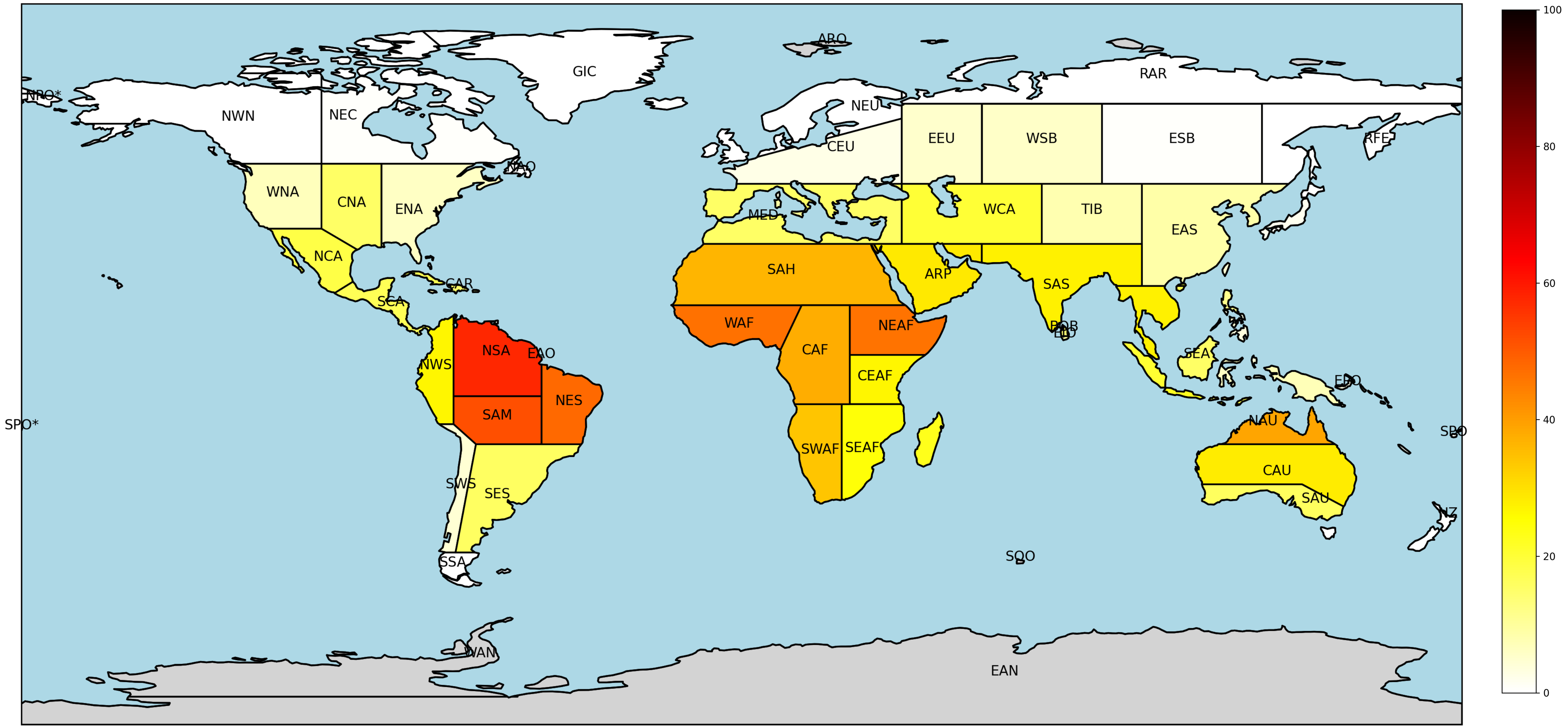
Media TX35 su regioni IPCC AR6 (solo terraferma) - gwl1.0



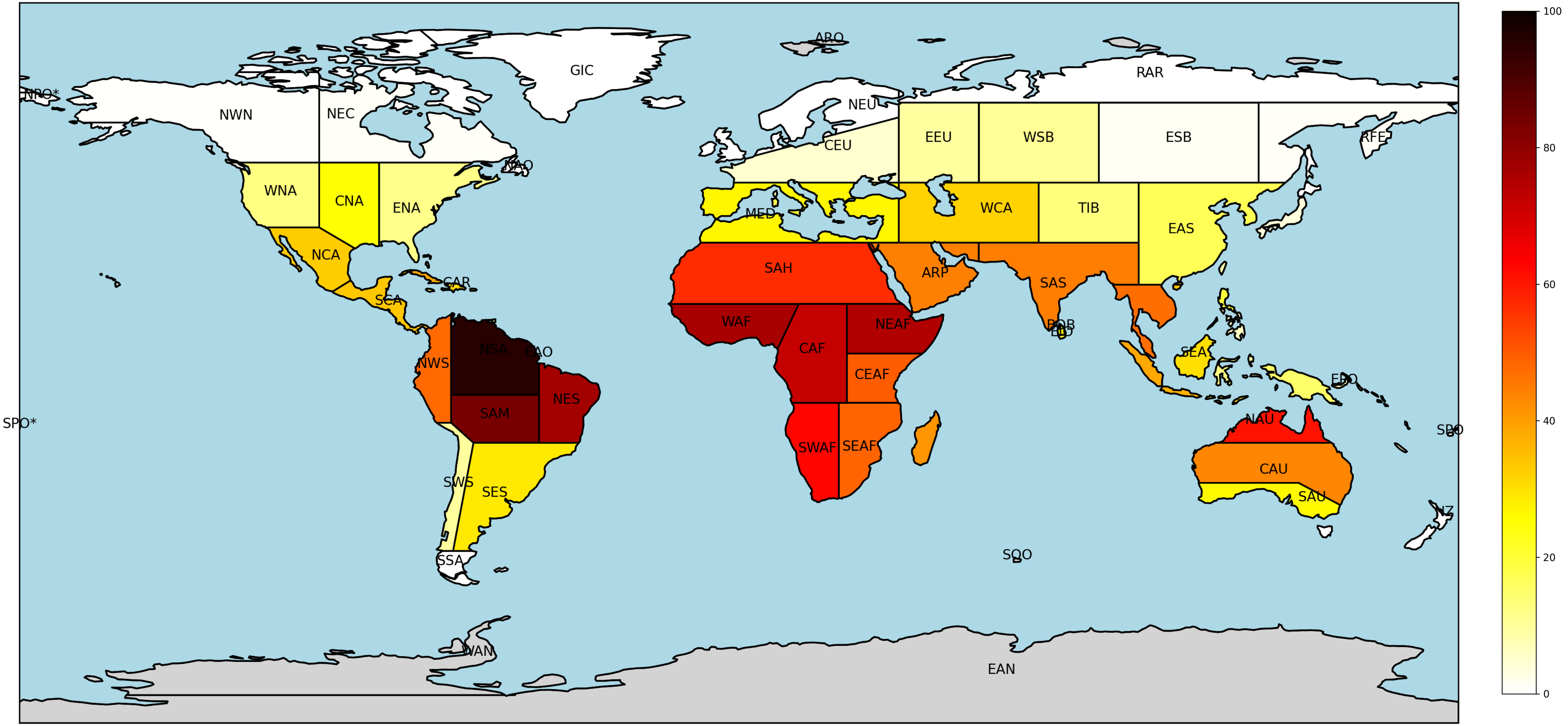
Media TX35 su regioni IPCC AR6 (solo terraferma) - gwl1.5



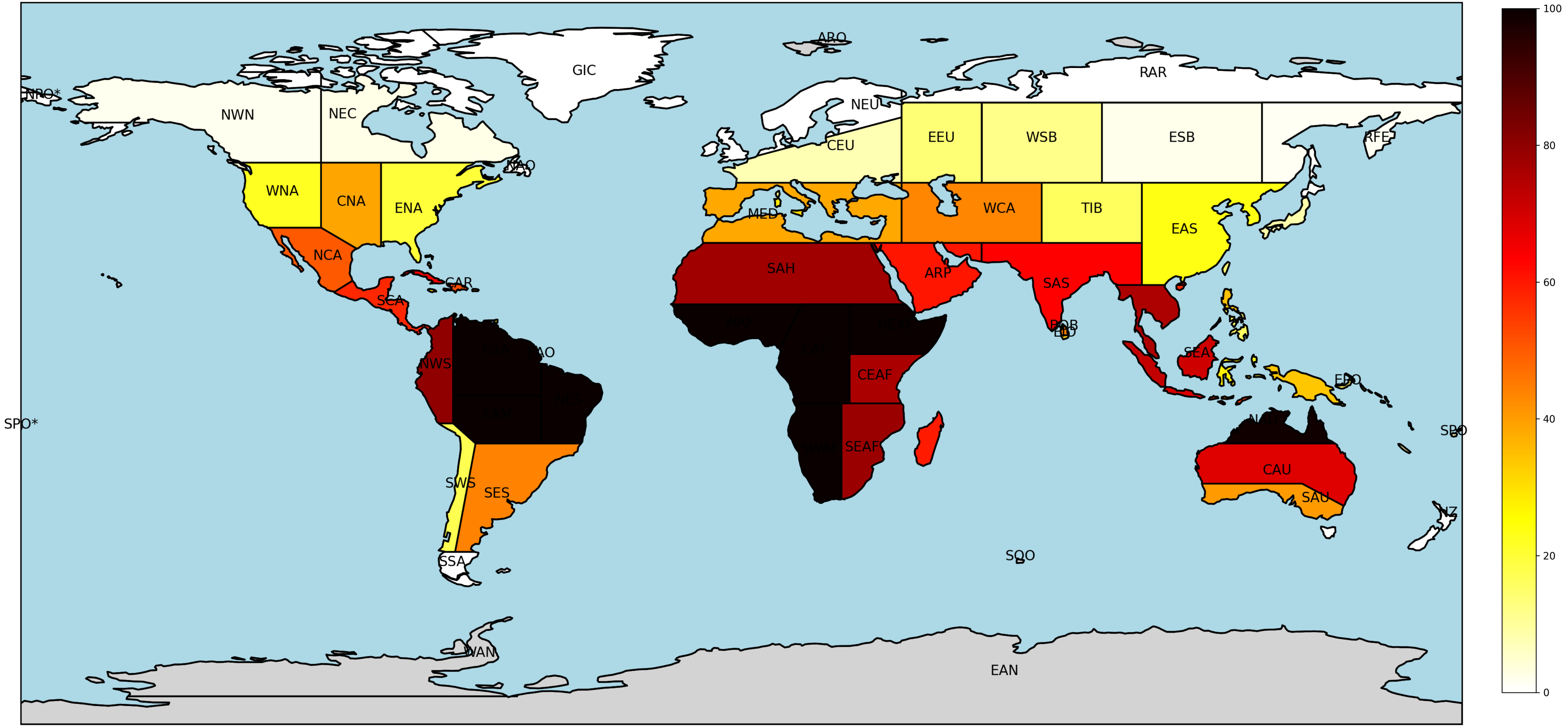
Media TX35 su regioni IPCC AR6 (solo terraferma) - gwl2.0



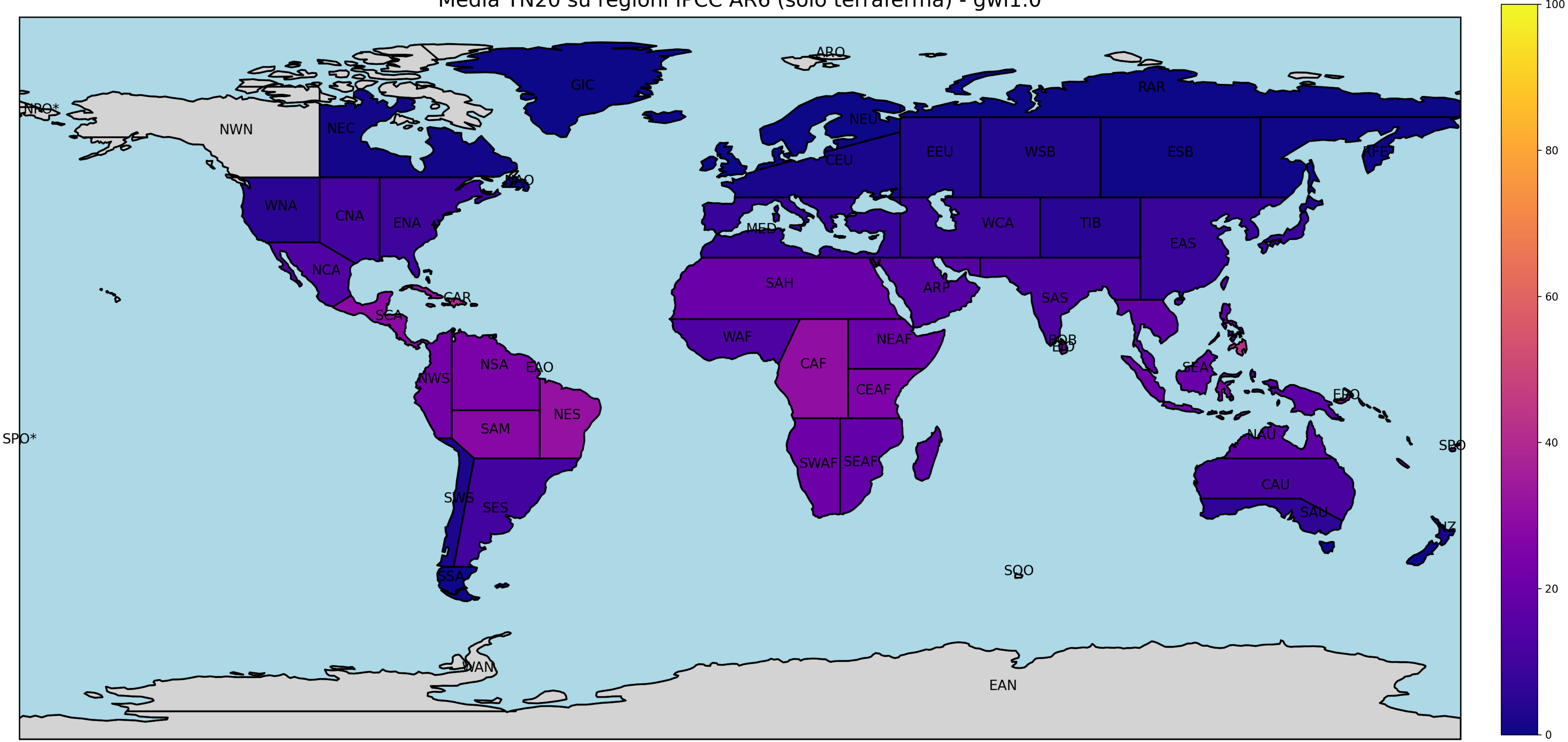
Media TX35 su regioni IPCC AR6 (solo terraferma) - gwl3.0

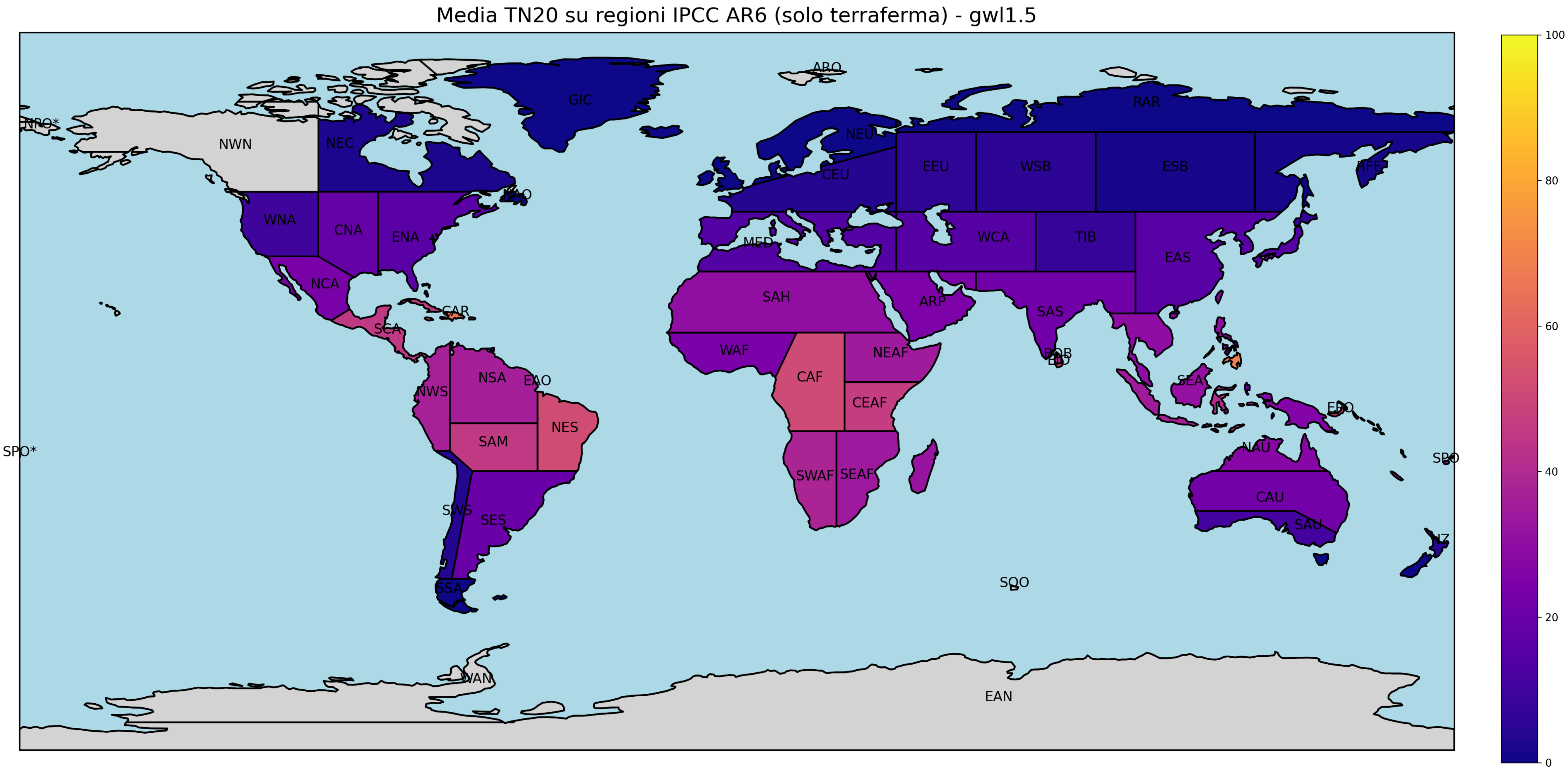


Media TX35 su regioni IPCC AR6 (solo terraferma) - gwl4.0



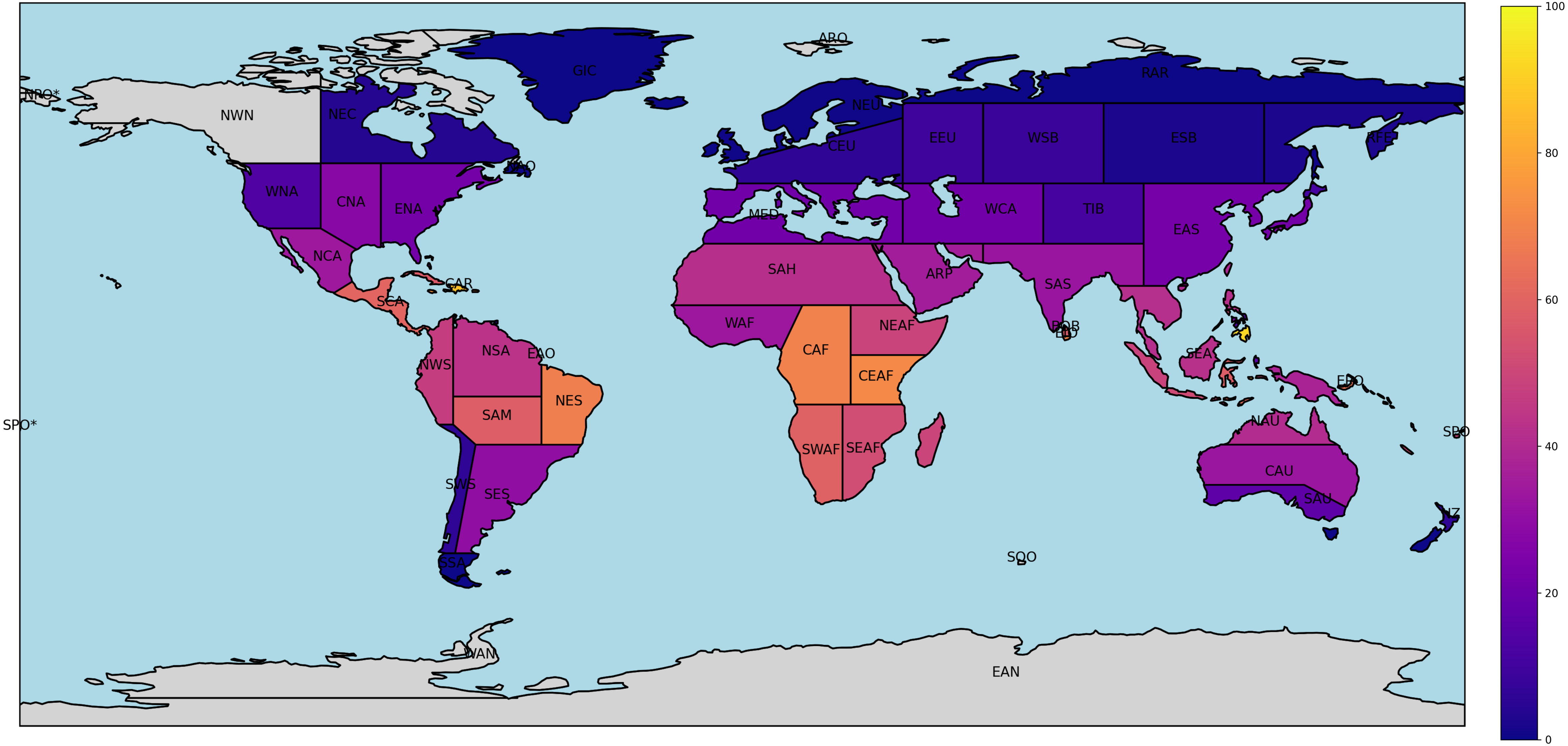
Media TN20 su regioni IPCC AR6 (solo terraferma) - gwl1.0



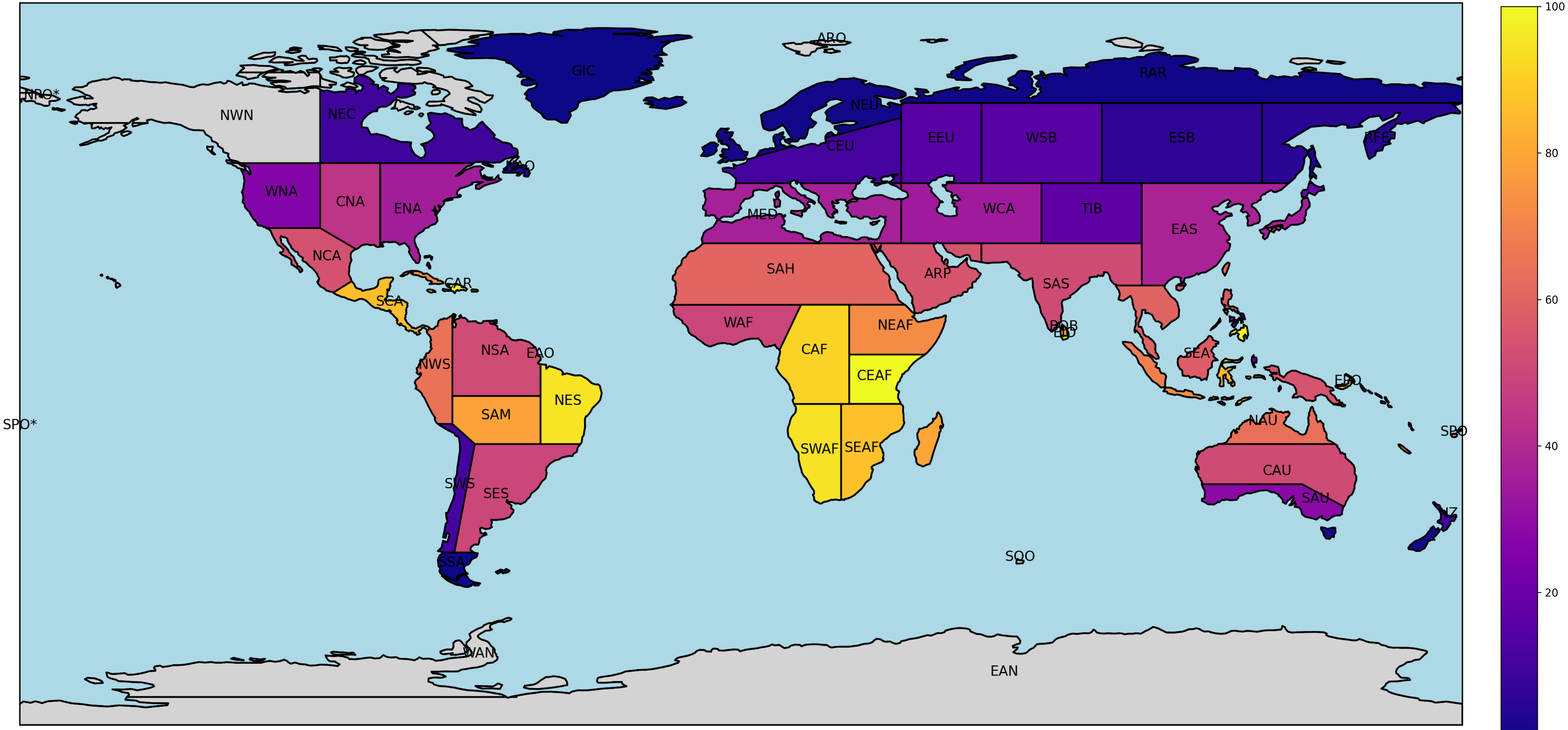


Media TN20 su regioni IPCC AR6 (solo terraferma) - gwl1.5
NWN
NEC
GIC
ARO
RAR
NEU
CEU
EEU
WSB
ESB
RFE
WNA
CNA
ENA
NAO
MED
WCA
TIB
EAS
NCA
CAR
SCA
SAH
ARP
SAS
WAF
CAF
NEAF
CEAF
BOB
EIO
SEA
NSA
EAO
NWS
SAM
NES
SWAF
SEAF
EPO
NAU
CAU
SAU
SPO
SPO*
SWS
SES
SSA
SOO
NZ
WAN
EAN
100
80
60
40
20
0

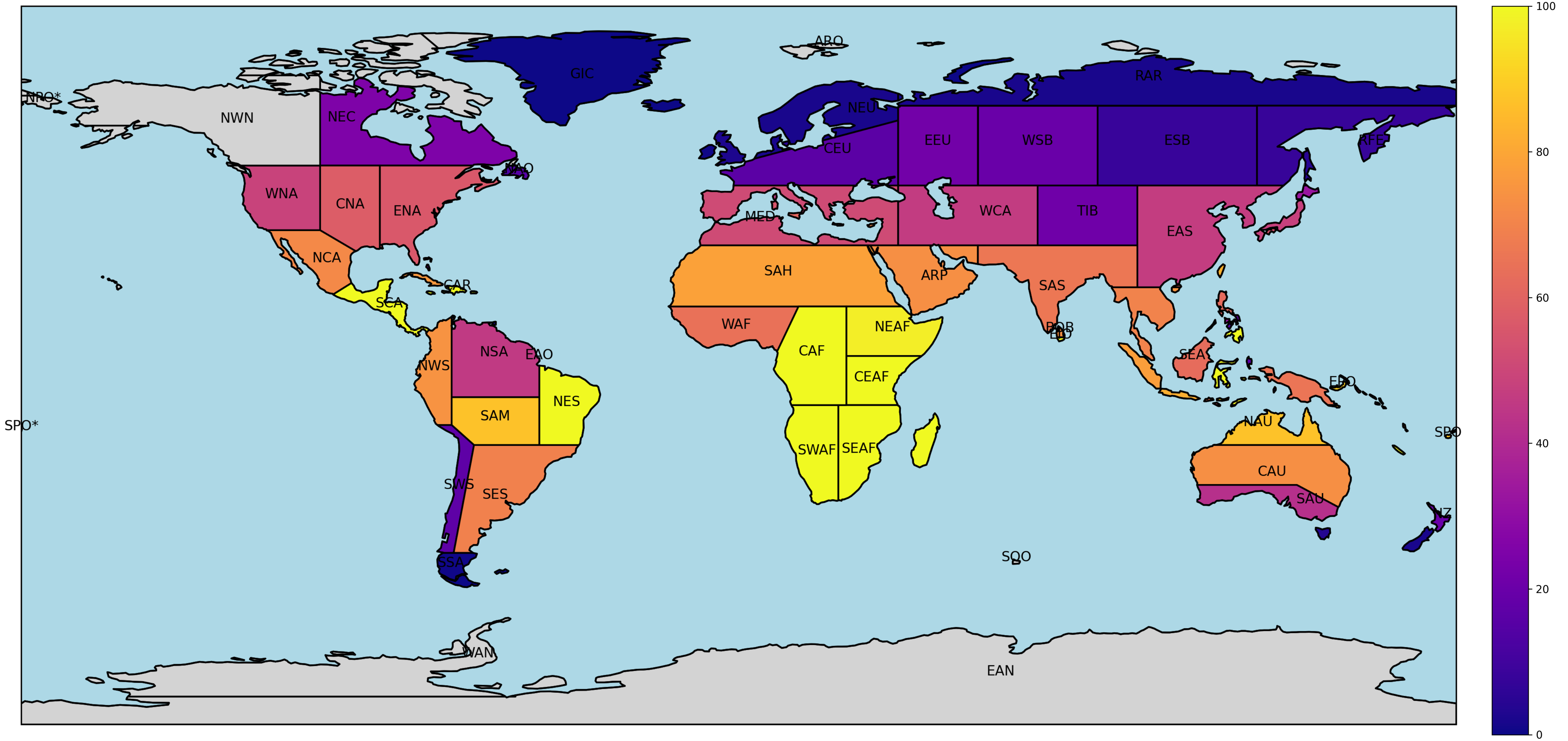
Media TN20 su regioni IPCC AR6 (solo terraferma) - gwl2.0



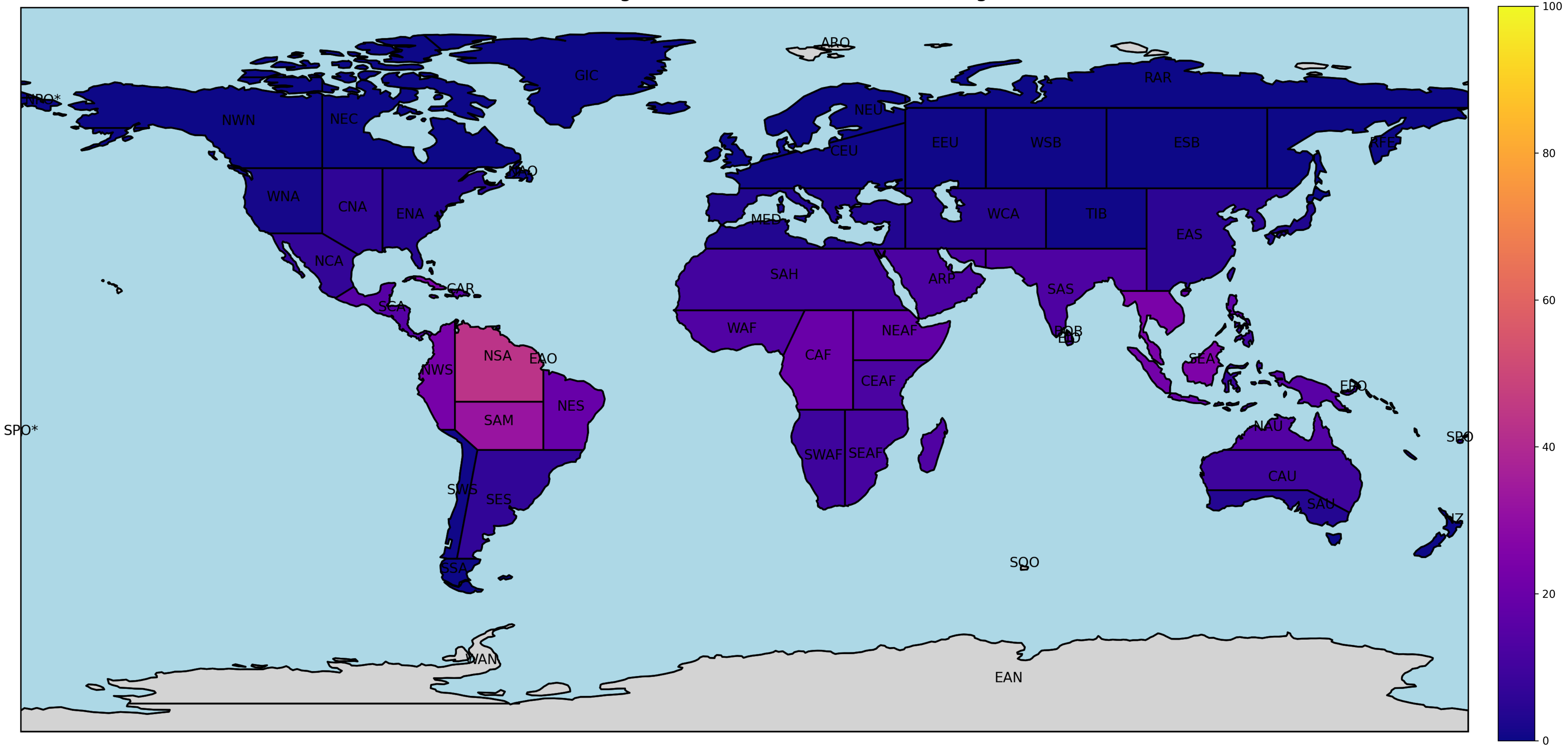
Media TN20 su regioni IPCC AR6 (solo terraferma) - gwl3.0



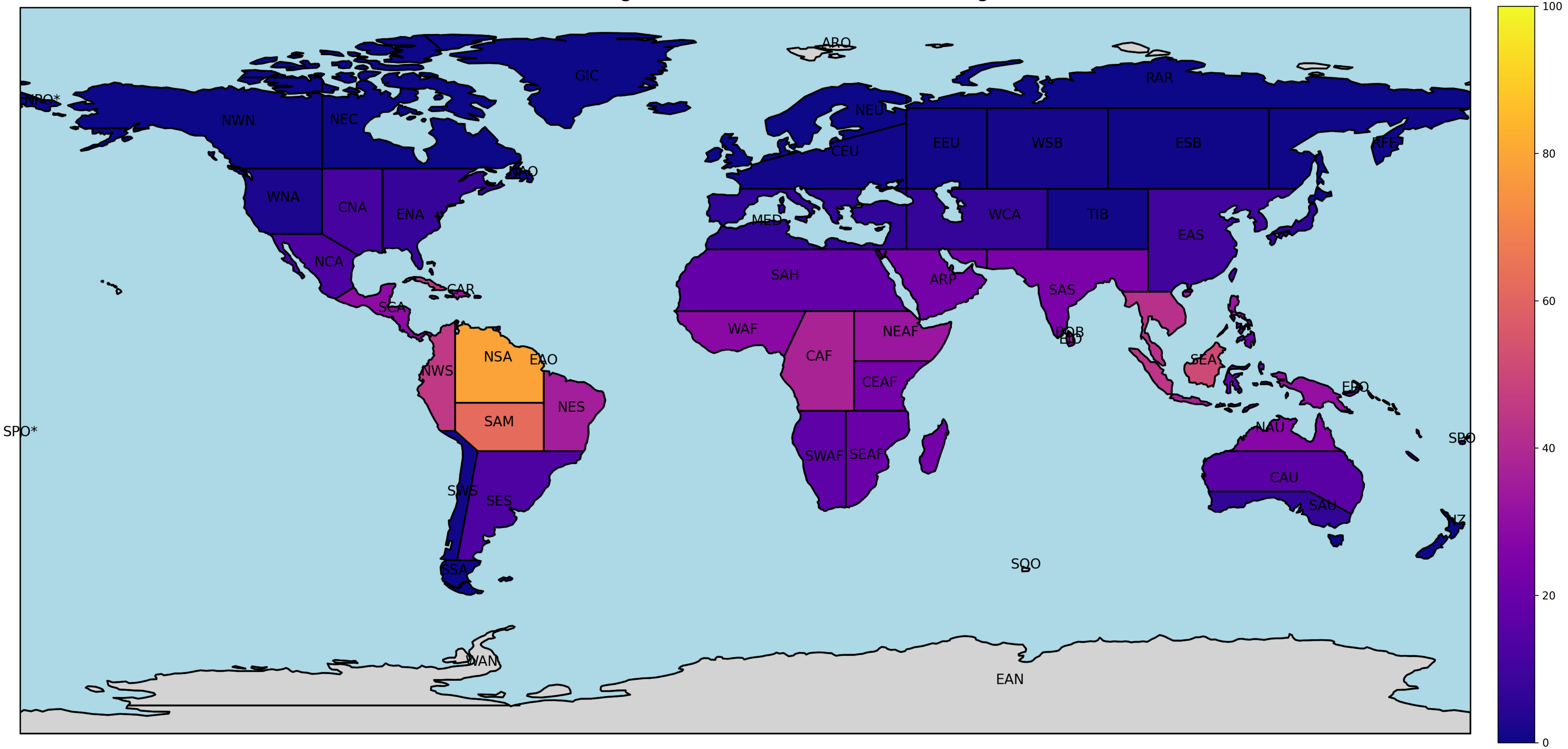
Media TN20 su regioni IPCC AR6 (solo terraferma) - gwl4.0

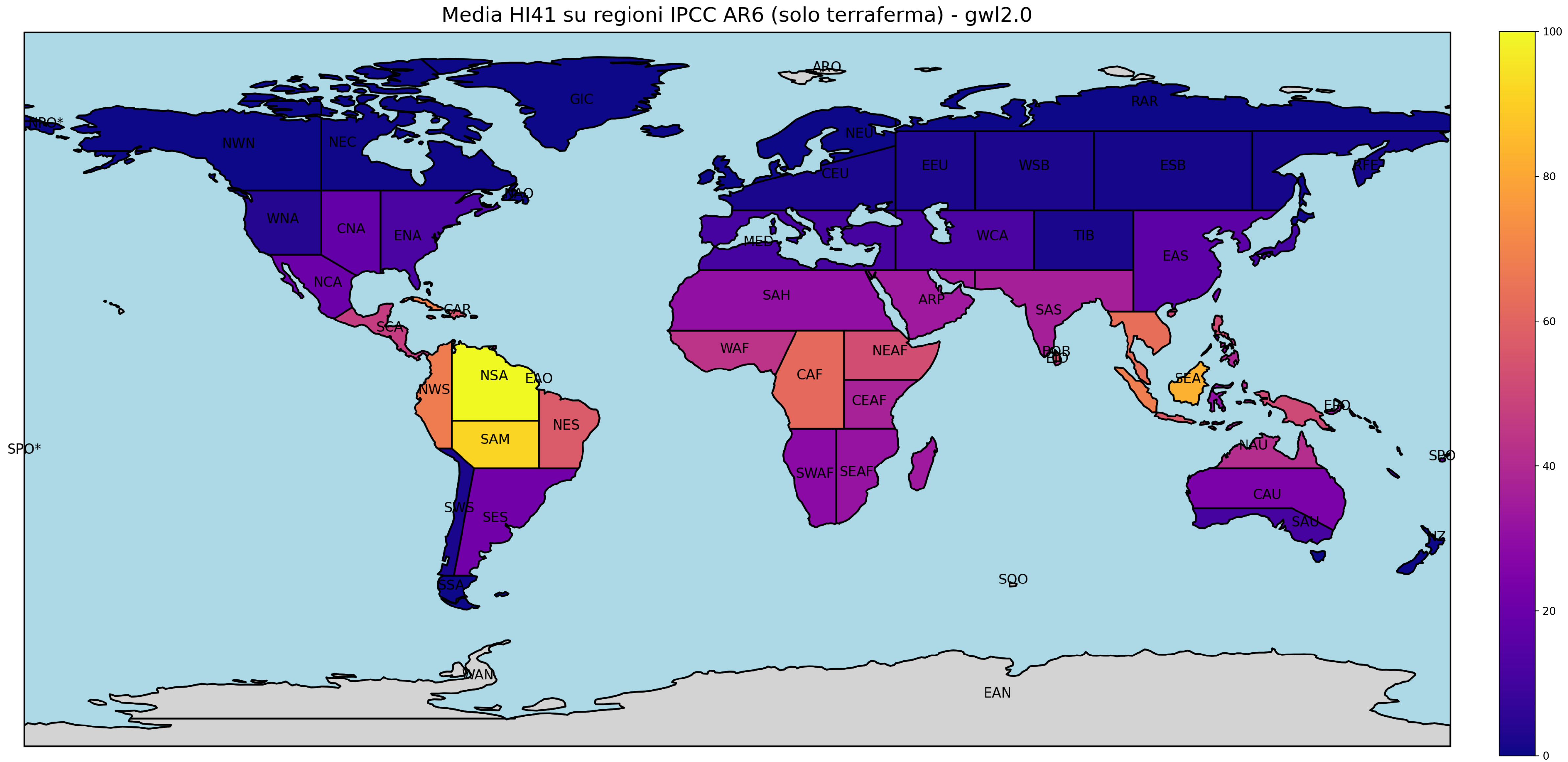


Media HI41 su regioni IPCC AR6 (solo terraferma) - gwl1.0

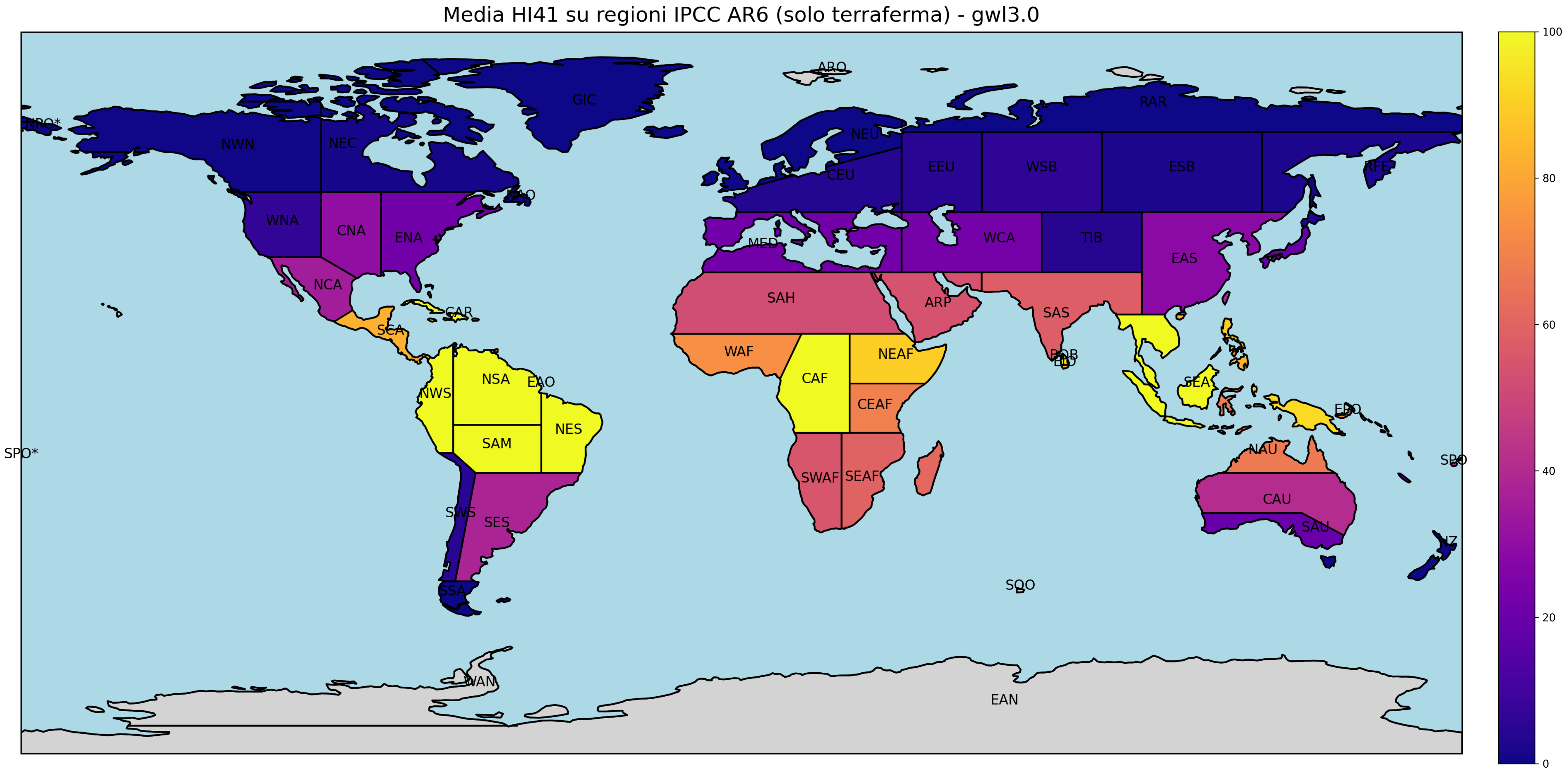


Media HI41 su regioni IPCC AR6 (solo terraferma) - gwl1.5

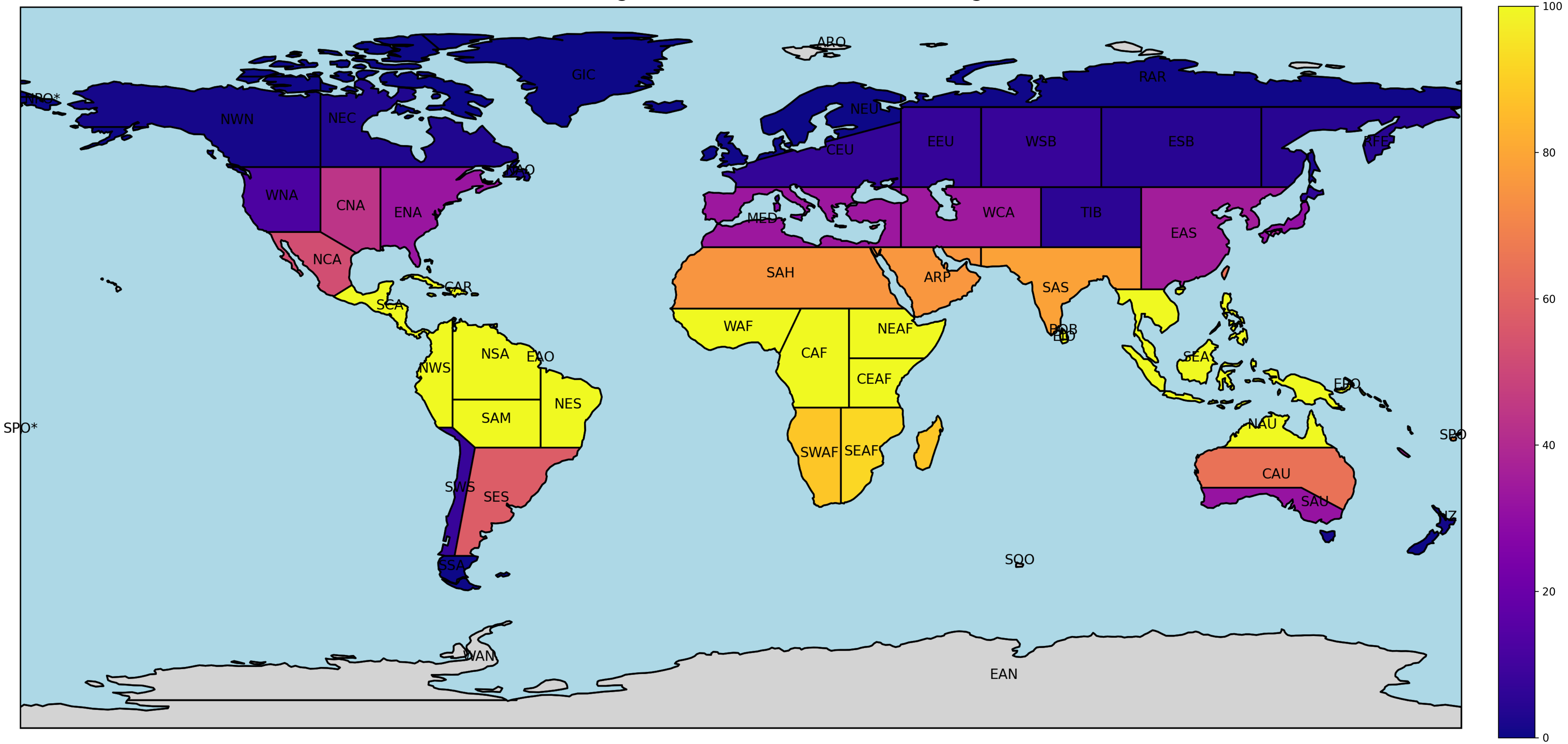




Media HI41 su regioni IPCC AR6 (solo terraferma) - gwl2.0
ARO
GIC
RAR
NWN
NEC
NEU
EEU
WSB
ESB
RFE
CEU
NAO
WNA
CNA
ENA
MED
WCA
TIB
EAS
NCA
SAH
ARP
SAS
CAR
SCA
WAF
NEAF
CAF
BOB
NSA
EAO
NWS
SEA
CEAF
EPO
SAM
NES
NAU
SPO*
SPO
SWAF
SEAF
CAU
SWS
SES
SAU
SOO
SSA
WAN
EAN
100
80
60
40
20
0


Media HI41 su regioni IPCC AR6 (solo terraferma) - gwl3.0
ARO
GIC
RAR
NWN
NEC
NEU
EEU
WSB
ESB
RFE
CEU
NAO
WNA
CNA
ENA
MED
WCA
TIB
EAS
NCA
SAH
ARP
SAS
CAR
SCA
WAF
NEAF
CAF
NSA
EAO
NWS
CEAF
SEA
NES
SAM
SPO*
NAU
SPO
SWAF
SEAF
CAU
SWS
SES
SAU
SSA
SOO
WAN
EAN
100
80
60
40
20
0

Media HI41 su regioni IPCC AR6 (solo terraferma) - gwl4.0

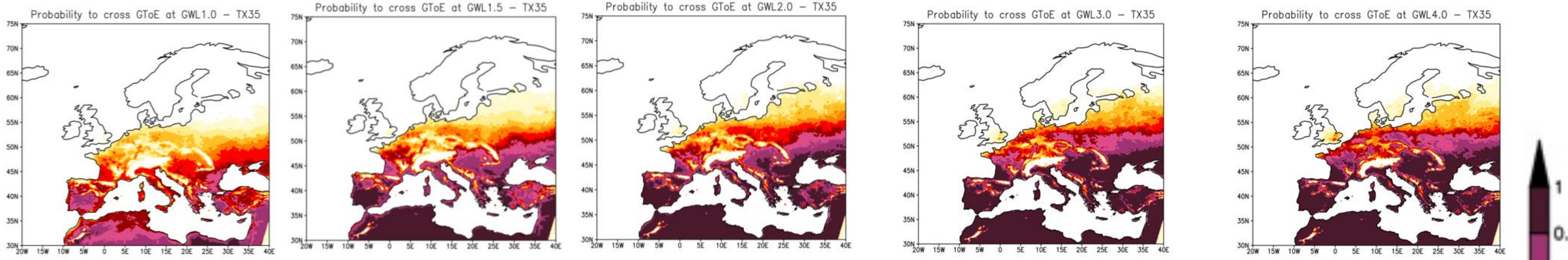


The method: the probability to cross the *GToE*

The probability of reaching a specific GWL threshold is then estimated for each Climatic Impact Driver (CID) and each region of interest.
We will use GWL 1.0, 1.5, 2.0, 3.0 and 4.0 as thresholds and we will evaluate the probability of crossing them for the CIDs chosen as representative of the climate stress in a particular region.

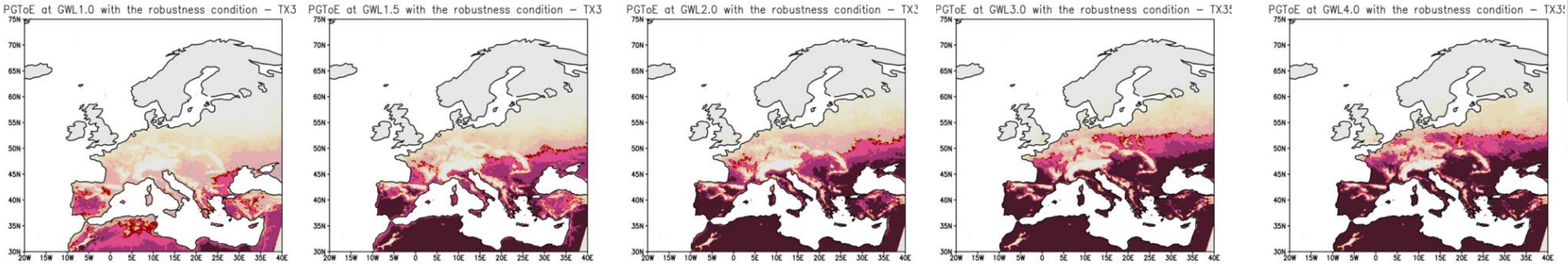
We applied a standard method based on the signal-to-noise ratio exceedance of a specified threshold (taken as one) (Hawkins and Sutton, 2012), but enriched with the condition for the "**change robustness**":
a grid-point emergence occurs when the forced change is considered robust, that is when at least 66% of the models have a signal-to-noise ratio greater than one and at least 80% of them agree on the sign of change.
The signal-to-noise ratio is estimated for each model from the ratio between the change and the standard deviation of non-overlapping 20-year means of the corresponding pre-industrial simulation;
for Euro-CORDEX simulations, the reference period for the standard deviation will be 1970-1999.

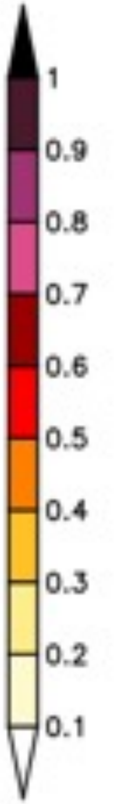
GWL1.0 GWL1.5 GWL2.0 GWL3.0 GWL4.0

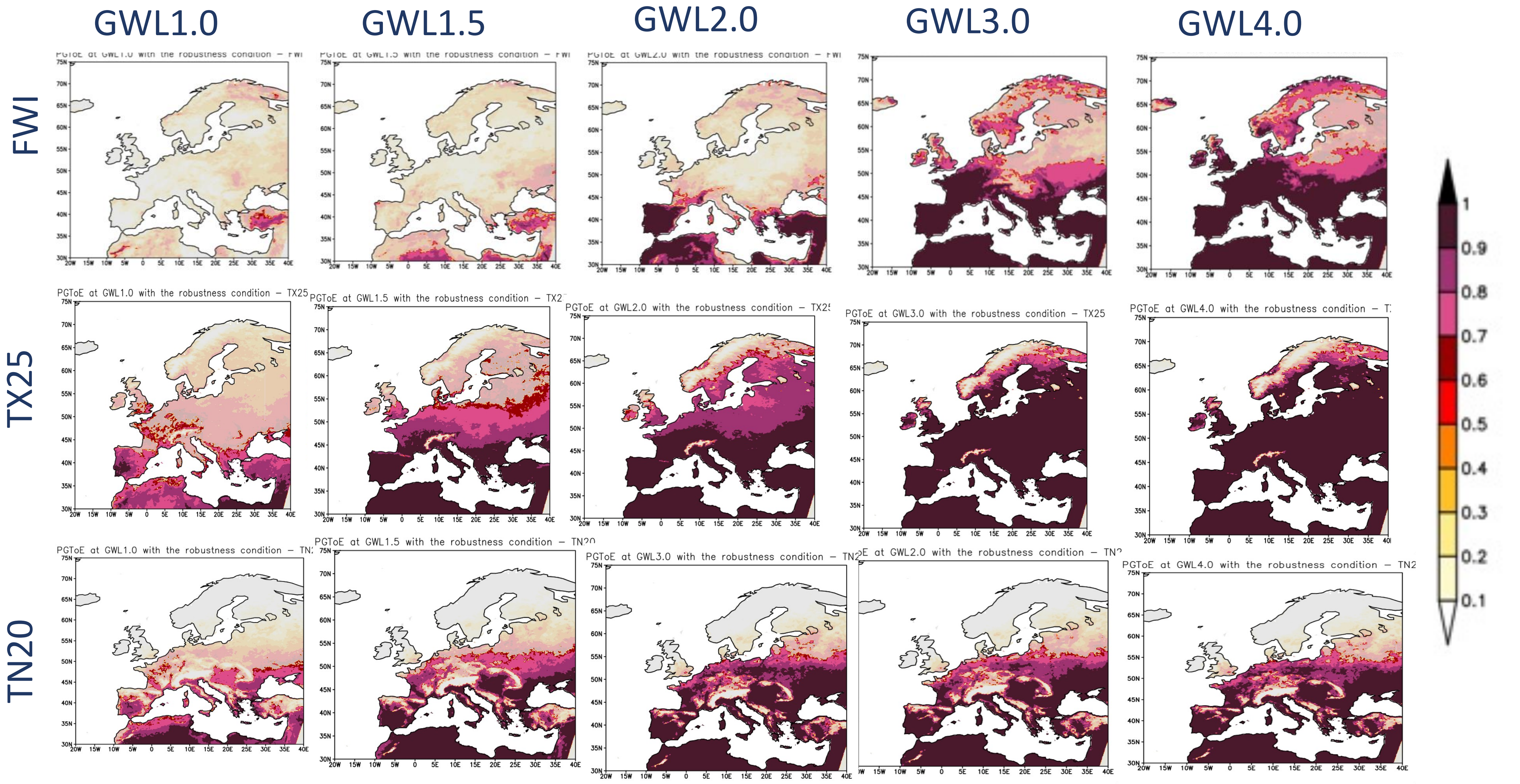


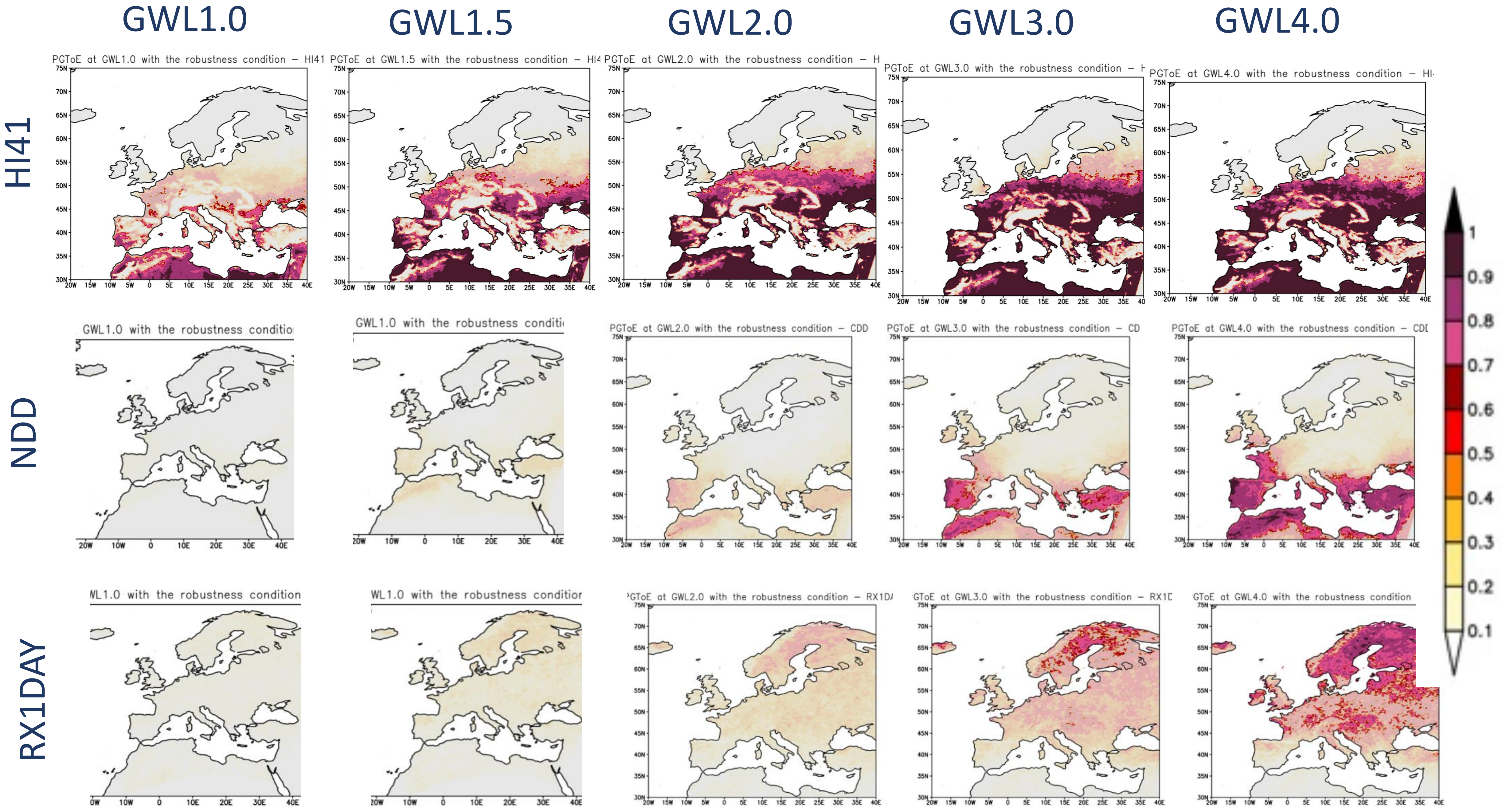
the combination of the two conditions: at least 66% of the models have a signal-to-noise ratio greater than one and at least 80% of them agree on the sign of change

TX35






GWL1.0
GWL1.5
GWL2.0
GWL3.0
GWL4.0
FWI
TX25
TN20
PGToE at GWL1.0 with the robustness condition – TX25
PGToE at GWL1.5 with the robustness condition – TN20
PGToE at GWL3.0 with the robustness condition – TX25
PGToE at GWL4.0 with the robustness condition – TN2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1


GWL1.0
GWL1.5
GWL2.0
GWL3.0
GWL4.0
HI41
NDD
RX1DAY
PGToE at GWL1.0 with the robustness condition – HI41
PGToE at GWL1.5 with the robustness condition – HI4
PGToE at GWL2.0 with the robustness condition – H
PGToE at GWL3.0 with the robustness condition – H
PGToE at GWL4.0 with the robustness condition – HI
GWL1.0 with the robustness conditio
GWL1.0 with the robustness conditi
PGToE at GWL2.0 with the robustness condition – CDD
PGToE at GWL3.0 with the robustness condition – CD
PGToE at GWL4.0 with the robustness condition – CDD
WL1.0 with the robustness condition
WL1.0 with the robustness conditior
PGToE at GWL2.0 with the robustness condition – RX1DA
GToE at GWL3.0 with the robustness condition – RX1D
GToE at GWL4.0 with the robustness condition
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

Let’s start with the indices calculation: what do we need?

- daily time series of climatic variables (i.e.: maximum temperature and precipitation) for the historical period and the future scenario;
- GWLs timeslices of each model of my ensemble;
- CDO/NCO libraries to compute indices;

ICTP

CDO-ECA

We are going to use a set of CDO operators to compute climate indices of daily temperature and precipitation extreme developed in the frame of European Climate Assessment (ECA) project.

https://earth.bsc.es/gitlab/ces/cdo/raw/b4f0edf2d5c87630ed4c5ddee5a4992e3e08b06a/doc/cdo_eca.pdf

Where are the data you can use?

- /home/esp-shared-a/GlobalModels/**CMIP5/daily/historical**
- /home/esp-shared-a/GlobalModels/**CMIP5/daily/rcp26**
- /home/esp-shared-a/GlobalModels/**CMIP5/daily/rcp85**

- /home/clima-archive5/**CMIP6/${mod}/historical**
- /home/clima-archive5/**CMIP6/${mod}/ssp585**
- /home/clima-archive5/**CMIP6/${mod}/ssp126**
- /home/clima-archive5/**CMIP6/${mod}/ssp370**

- /home/esp-shared-a/RegionalModels/CORDEX/**EUR-11/historical/**
- /home/esp-shared-a/RegionalModels/CORDEX/**EUR-11/rcp26/**
- /home/esp-shared-a/RegionalModels/CORDEX/**EUR-11/rcp85/**

PREPARE the data:

1. Daily time series of the variables (pr, tas, tasmax, tasmin...)
2. Convert the units in the correct ones if needed!!

e.g.: cdo mulc,86400 infile.nc outfile.nc (to change units from "kg m-2 s-1" to “mm/day”)
cdo subc,273.15 infile.nc outfile.nc (to change units from “Kelvin” to “degrees Celsius”)

3. Select the Reference period (e.g.: 1995-2014):
cdo -selyear,1995/2014 infile.nc outfile.nc

4. Select the timeslices in the future according to the GWL for a given scenario:
- search for the CMIP5/CMIP6 driver of your data in:

/home/netapp-clima-scratch/fraffael/WORKSHOP/cmip5_warming_levels_all_ens_1850_1900_MIX-EUR11.csv

ICTP

Searching for GWLs:

If you open "cmip5_warming_levels_all_ens_1850_1900_MIX-EUR11.csv":

model, ensemble, exp, warming_level, start_year, end_year
HadGEM2-ES r1i1p1 rcp85 4.0 2063 2082
HadGEM2-ES r2i1p1 rcp85 4.0 2063 2082
HadGEM2-ES r3i1p1 rcp85 4.0 2063 2082
HadGEM2-ES r4i1p1 rcp85 4.0 2060 2079
IPSL-CM5A-LR r1i1p1 rcp85 4.0 2056 2075
IPSL-CM5A-LR r2i1p1 rcp85 4.0 2057 2076
IPSL-CM5A-LR r3i1p1 rcp85 4.0 2056 2075
IPSL-CM5A-LR r4i1p1 rcp85 4.0 2054 2073
IPSL-CM5A-MR r1i1p1 rcp85 4.0 2057 2076
IPSL-CM5B-LR r1i1p1 rcp85 4.0 2075 2094
MPI-ESM-LR r1i1p1 rcp85 4.0 2072 2091
MPI-ESM-LR r2i1p1 rcp85 4.0 2071 2090
MPI-ESM-LR r3i1p1 rcp85 4.0 2071 2090
MPI-ESM-MR r1i1p1 rcp85 4.0 2073 2092

PREPARE the data:

5. Compute the index using the daily values for the reference and future timeslices

6. Compute the mean of each period:

```
cdo timmean tx35_ref.nc tx35_ref-mean.nc
cdo timmean tx35_gwl4.0.nc tx35_gwl4.0-mean.nc
```

7. Compute the change:

```
cdo sub tx35_gwl4.0-mean.nc tx35_ref-mean.nc tx35_gwl4.0ch.nc
```

How can I compute some of the indices seen so far?

- Here: /home/netapp-clima-scratch/fraffael/WORKSHOP/recipes/

CDDmax.readme CoolDD.readme CWDmax.readme
HeatDD.readme NDD.readme RX1DAY.readme
TN20.readme TX25.readme

PAY ATTENTION to the description files: they tell you the units you need to use to compute a specific index.