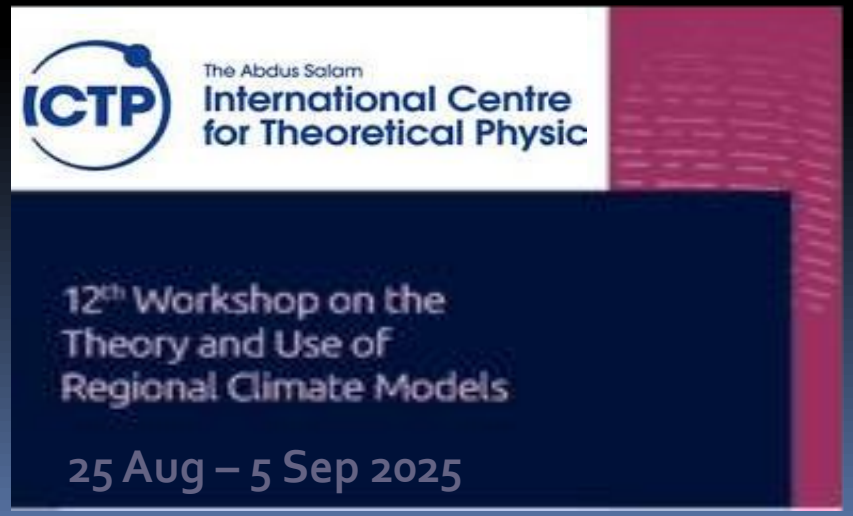
CMIP6 model evaluation of extreme climatic indices at regional scale in CORDEX-CAM

Ernesto Ramos Esteban, Tereza Cavazos, and Gabriela Colorado Ruiz

Dept. of Physical Oceanography, CICESE

Ensenada, B.C., Mexico



Departamento de
Oceanografía
Física

Content

1. Introduction
2. Data and methodology of extreme climate indices
3. Historical evaluation of GCMs
4. Trends and historical climatologies
5. Future changes
6. Discussion on changes of climate drivers

Introduction

An **extreme event** occurs when the value of a climate variable exceeds a threshold near the extremes of the observed range for that variable.

- **Heavy rainfall (R10, R95)**
- **CDD and CWD**
- **Extreme temperatures (TXx, TNn)**
- **etc.**

Climate Extreme Indices (CEI)

It is important to improve the quality and availability of climate information (historical/future) to support prevention and early warning systems.

Relevant for CORDEX studies and IPCC reports

Climate Extreme Indices (CEI)

Historical

Global Scale:

Donat et al., (2016): 14 ECI of Pr and T.

Kim et al., (2020): 26 ECI of Pr and T.

Regional Scale (Mexico):

Aguilar et al., (2005): 21 ECI of Pr and T in south Mex

Colorado-Ruiz & Cavazos (2021): **14 ECI** of Pr all Mex

Future projections

Global Scale (CMIP5):

Sillman et al., 2013: 26 indices of Pr and T.

Coppola et al., 2021: Hazard Indicators.

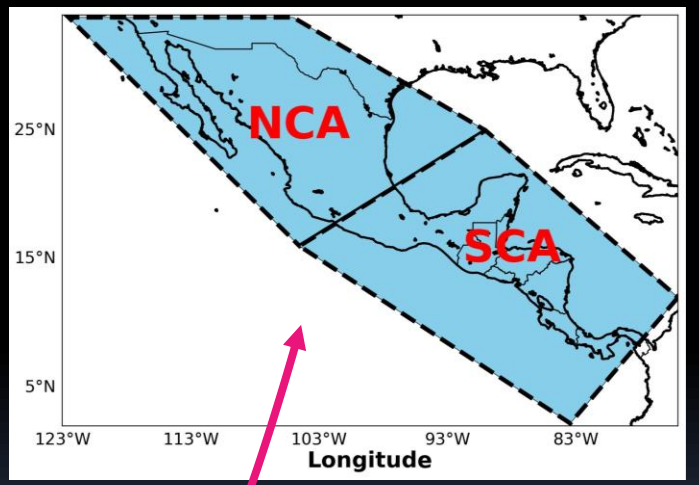
Regional Scale Latin America (CMIP6):

Almazroui et al., (2021): Projections of T and Pr.

Avila-Diaz et al., (2023): 16 ECI of historical trends and changes through mid 21st century

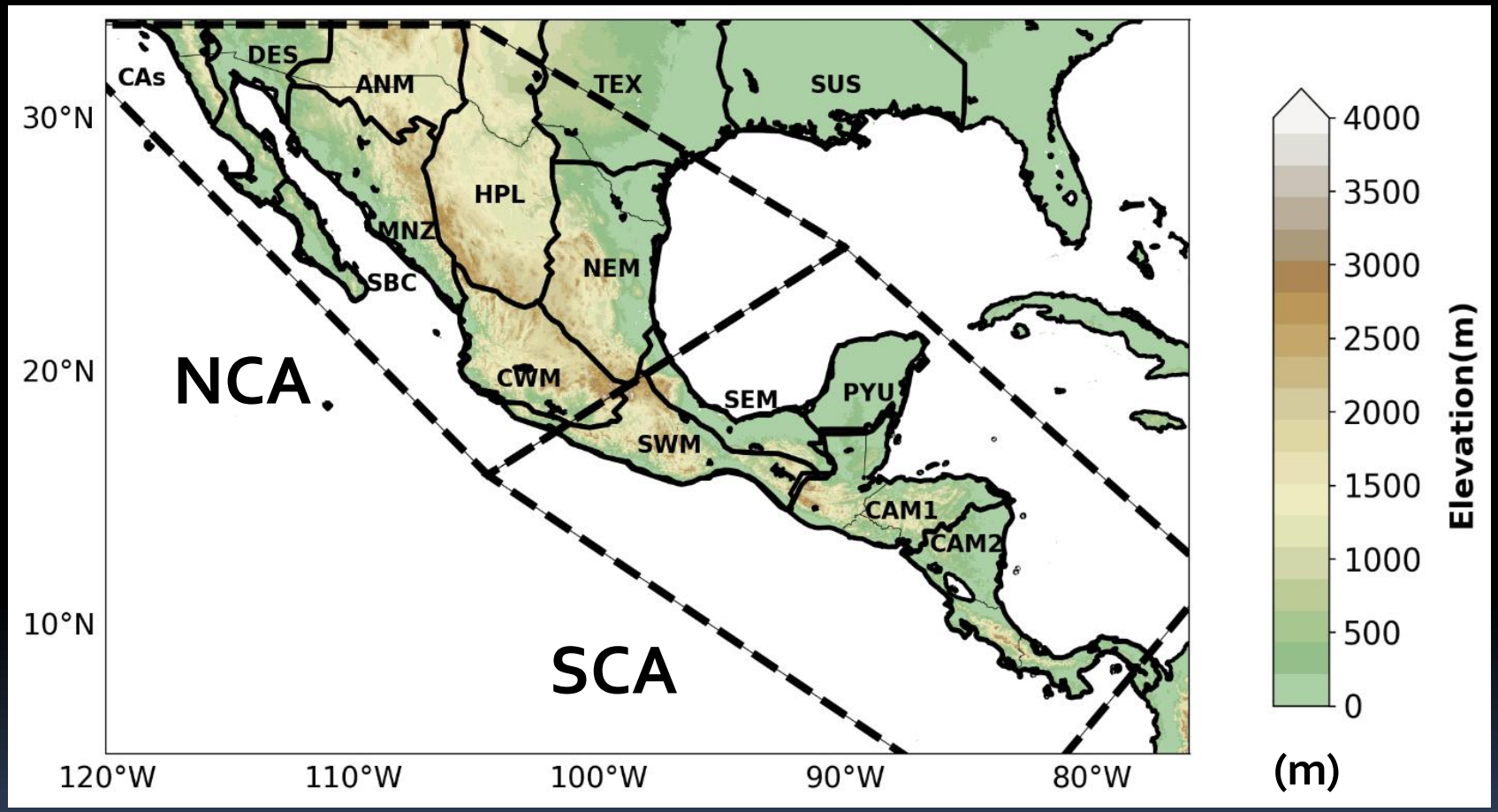
Zhao et al., (2023): 10 Indices of Pr in Namer.

Two large regions of the IPCC



Study regions

- **Two big regions** from the **IPCC AR6** (Iturbide et al., 2020)
- **13 climatic regions** defined by Colorado-Ruiz & Cavazos (2021)
- In addition, 2 regions in **Central America**



Data

CEI at anual scale for ERA5 and CMIP6* models

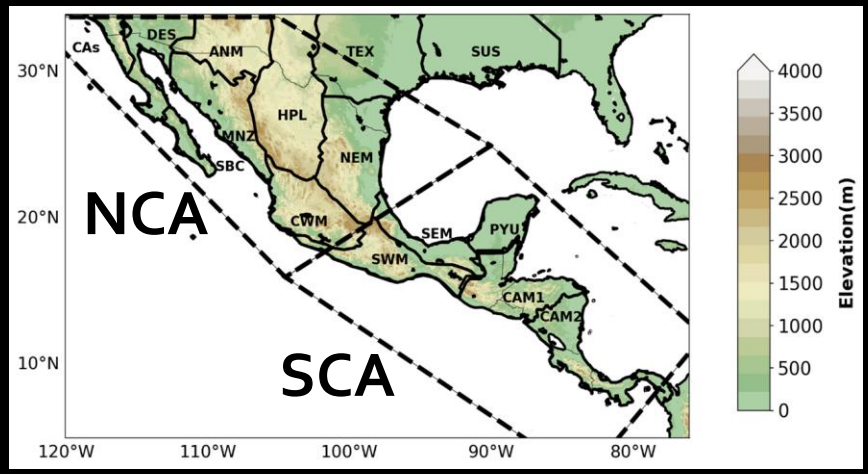
Climate Extreme Index (CEI)	Index	Units
Consecutive dry days	CDD	Days
Annual total wet day precipitation	PRCPTOT	mm
Number of heavy precipitation days	R10mm	Days
Extremely wet days	R95p	mm
Diurnal temperature range	DTR	deg C
Maximum daily maximum temperature	TXx	deg C
Minimum daily minimum temperature	TNn	deg C

(Zhang et al., 2011)

* https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-extreme-indices-cmip6?tab=doc

Scientific Questions

- Which temperature and precipitation extreme indices show significant trends in regions **of Mexico**, the southern United States, and Central America during 1981–2010?
- Are the mean conditions of the ECI and trends well represented by the CMIP6 models?
- What are the possible changes in frequency and intensity of extreme events during the 21st century under two scenarios (SSP2 4.5 and SSP3 7.0) of global warming?



Data

Evaluation

1. ERA5 as reference for "observed" climate extreme indices at annual scale

- Spatial resolution: 0.25° x 0.25°
- Historical period: 1981–2010
- Available at the Copernicus Climate Data Store.

Historical and Future projections

2. Climate Extreme Indices of temperature and precipitation from CMIP6:

- **10 GCMs from CMIP6 and their median ensemble**
- Periods: 1981–2010 (reference) and future (2021–2040, 2041–2060, 2081–2099)
- Spatial resolution: ~1.0 ° x 1.0°
- CEI obtained from the database of Sandstad et al., (2022):

https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-extreme-indices-cmip6?tab=doc

Metrics of Evaluation (30-year periods)

- **Taylor Skill Score** (Taylor, 2001) - spatial skill of the GCMs relative to the reference (ERA5). This is calculated using the mean climatological values for each CEI. ➔ TSS [0 to 1].

$$\mathbf{TSS} = \frac{(\mathbf{1} + \boldsymbol{R})^{\mathbf{4}}}{\mathbf{4}\left(\boldsymbol{STDr} + \frac{\mathbf{1}}{\boldsymbol{STDr}}\right)^{\mathbf{2}}}$$

R = Horizontal Pearson correlation
STDr = Ratio of the model (horizontal) STD to the ref. STD (ERA5)

- **BIAS:** difference between the mean climatological model results of a CEI and the reference calculated in each grid point or region:

$$\mathbf{BIAS} = \frac{1}{n}\sum_{k=1}^{n}(Cm_k) - \frac{1}{n}\sum_{k=1}^{n}(Co_k) = \overline{\mathrm{Cmod}} - \overline{\mathrm{Cobs}}$$

$\mathbf{Cm_k}$ = Model
$\mathbf{Co_k}$ = Reference (ERA5)
n = number of years

Comprehensive Ranking Metric (RM)

Comprehensive ranking metric (Ahmed et al., 2019; Chen et al., 2011) combines different evaluation metrics to obtain the overall ranking of each GCM over the domain.

The RM of each model is obtained according to the CEI and region:

$$\boldsymbol{RM_i} = 1 - \frac{1}{\mathrm{nm}} \sum_{j=1,}^{m} rank_{ij}$$

i = 1, n represent the models,

j = 1, m represent the evaluation metrics (TSS, Bias, CV, etc.)

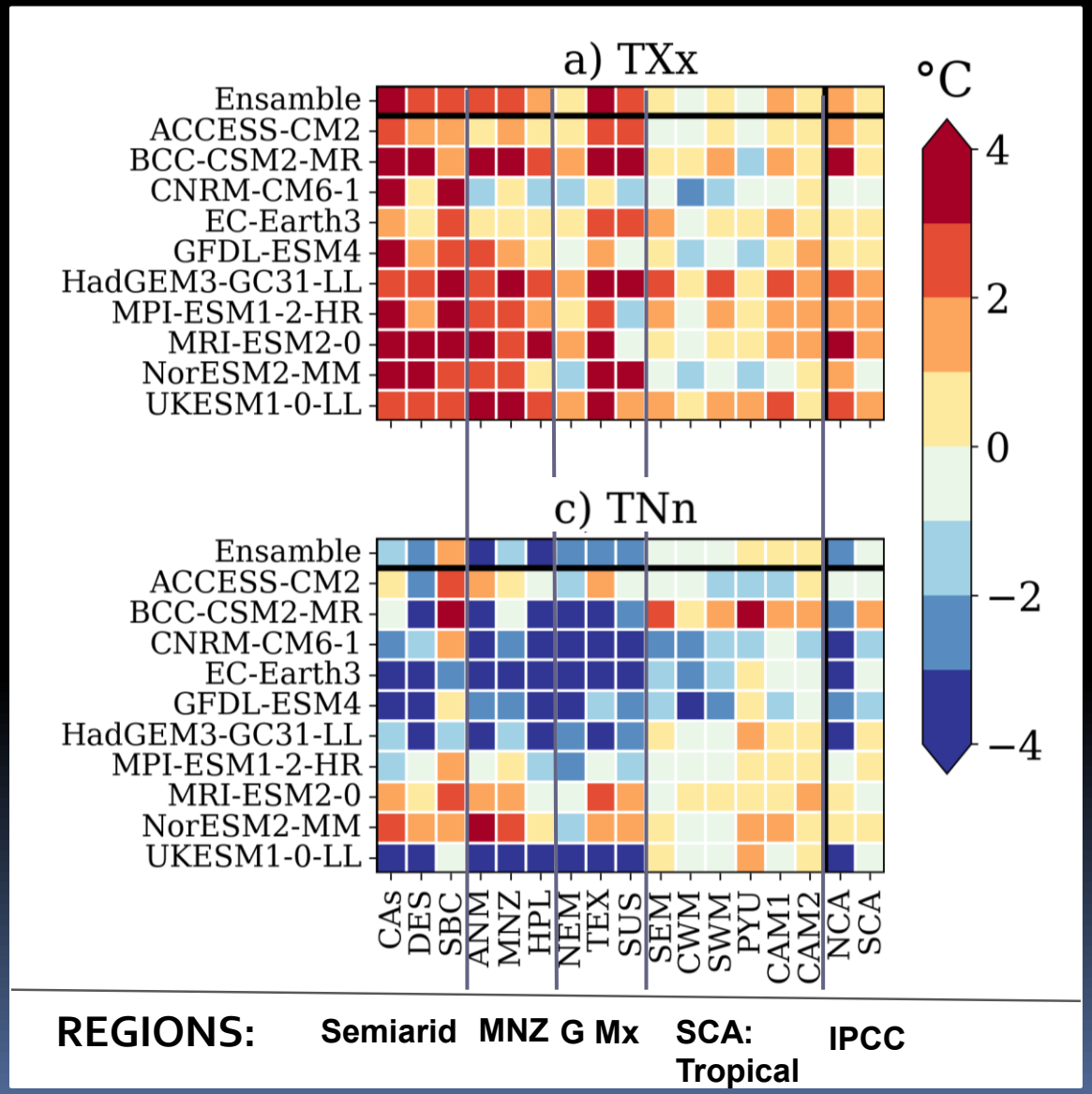
$\mathbf{rank_{ij}}$ ➔ represents the GCM's rank in each metric and region.

RM close to 1 indicates a model good skill.

Results: Spatial evaluation of GCMs

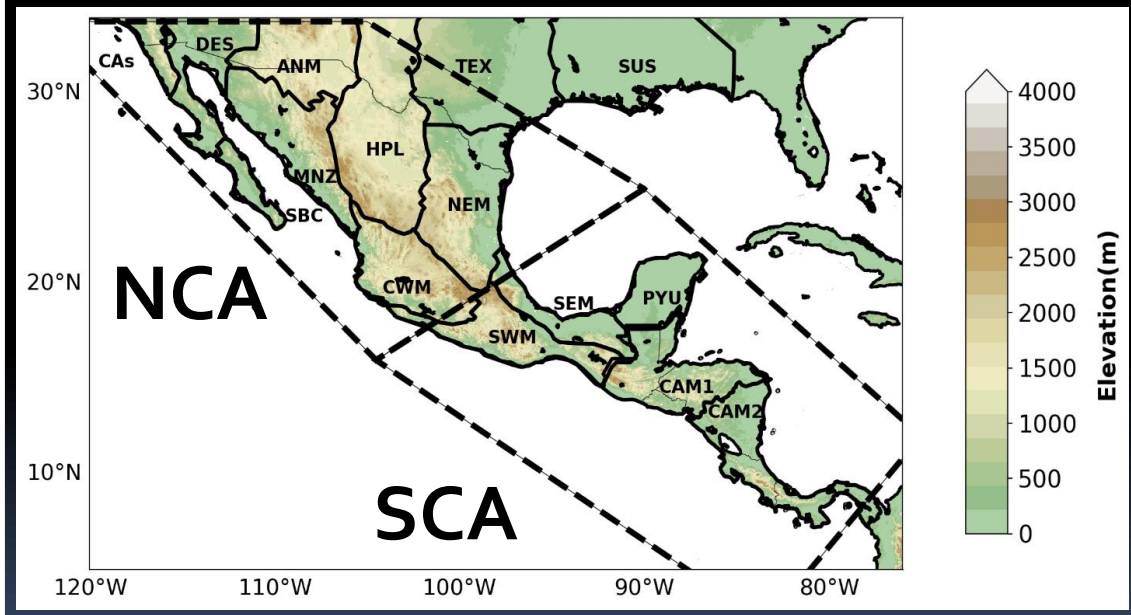
➔ Ranking of models (1981-2010)

Model BIAS

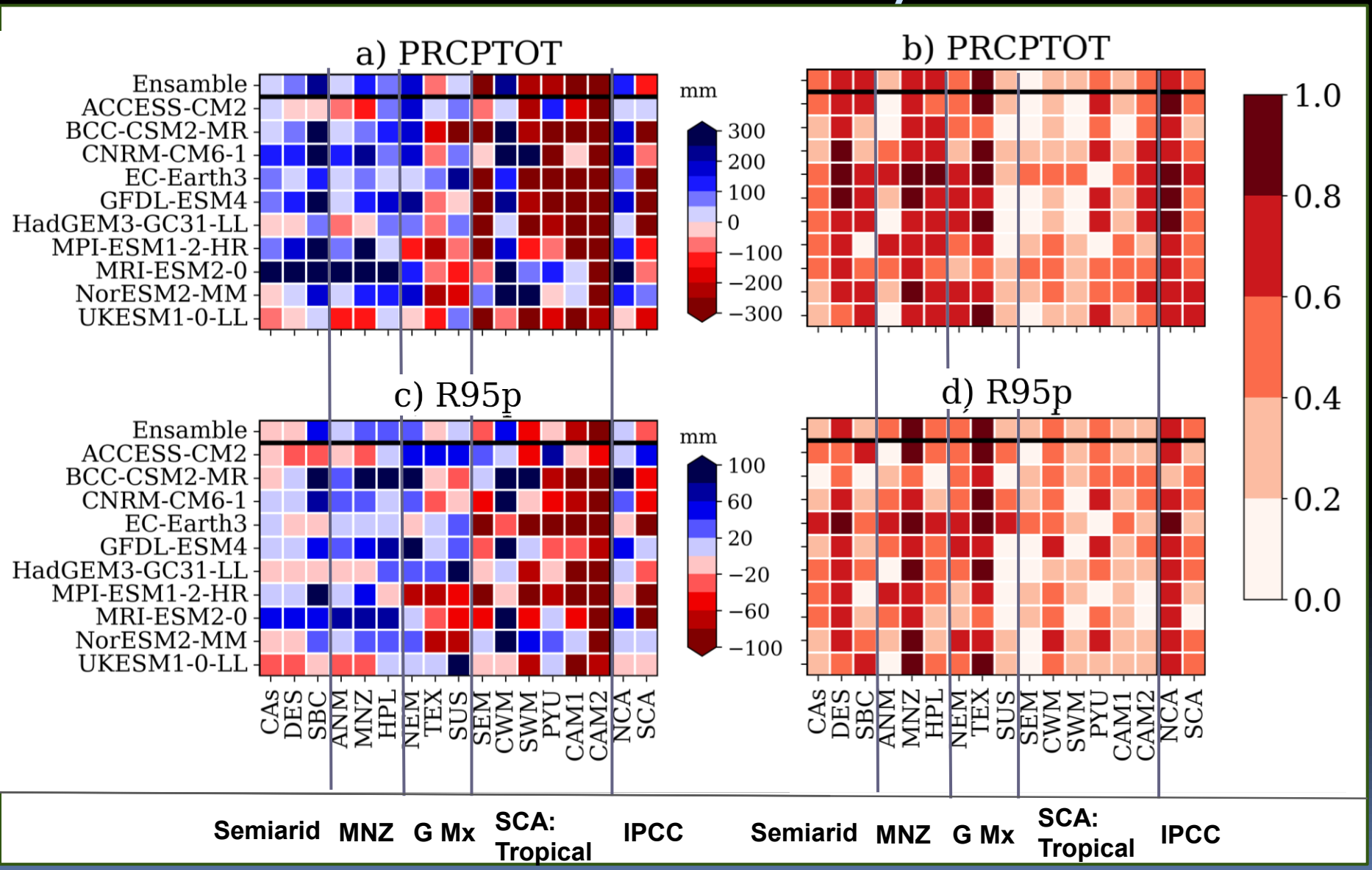


REGIONS: **Semiarid** **MNZ G Mx** **SCA: Tropical** **IPCC**

GCMs´ Evaluation (1981-2010)



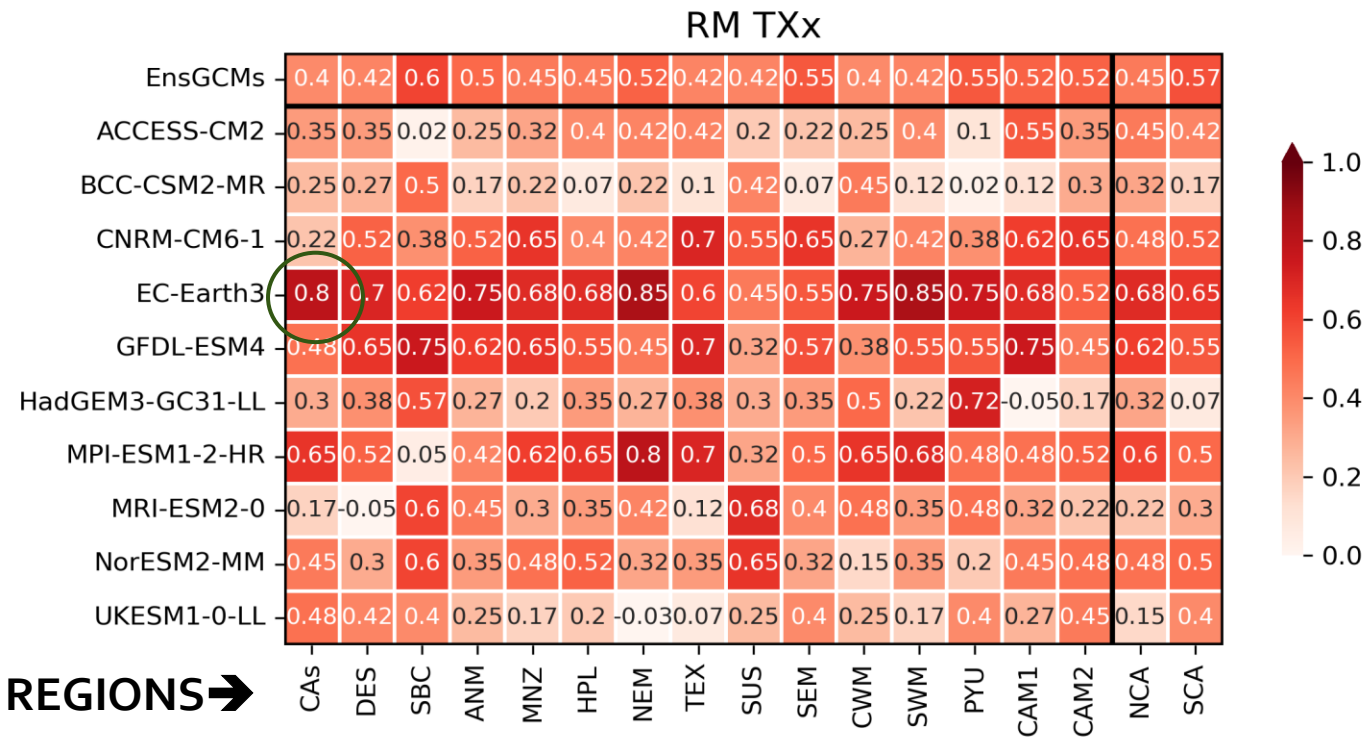
Model BIAS Taylor Skill score

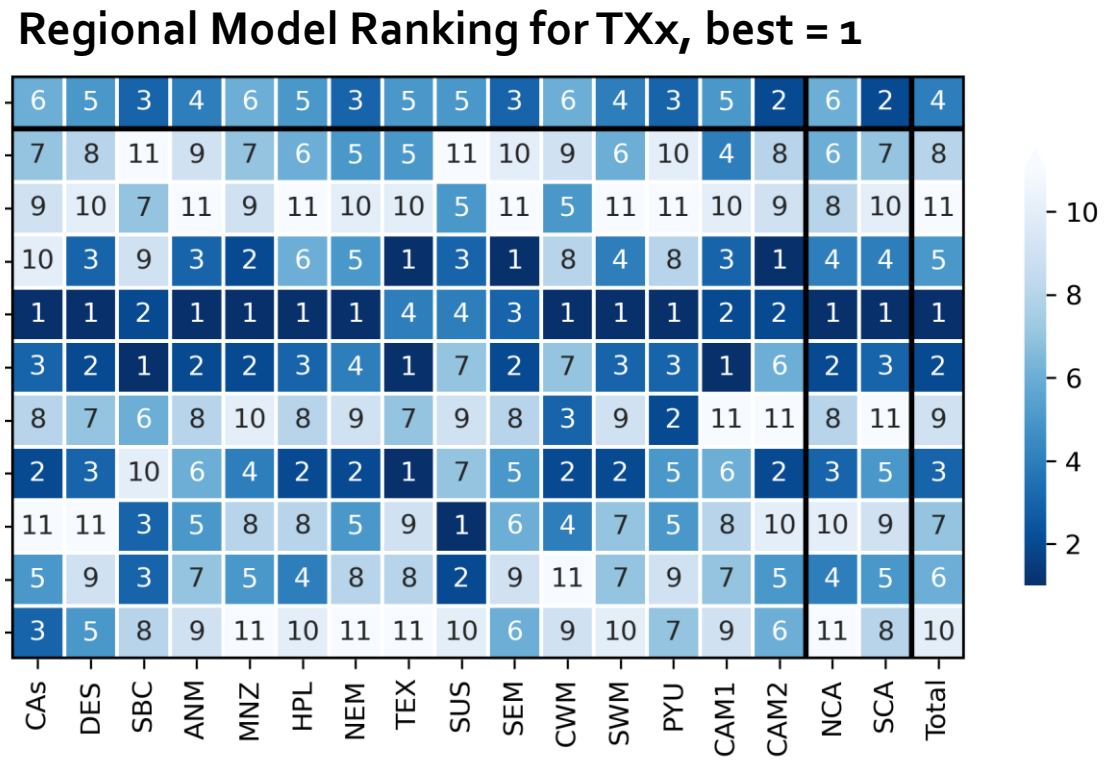


GCMs´ Ealuation (1981-2010)

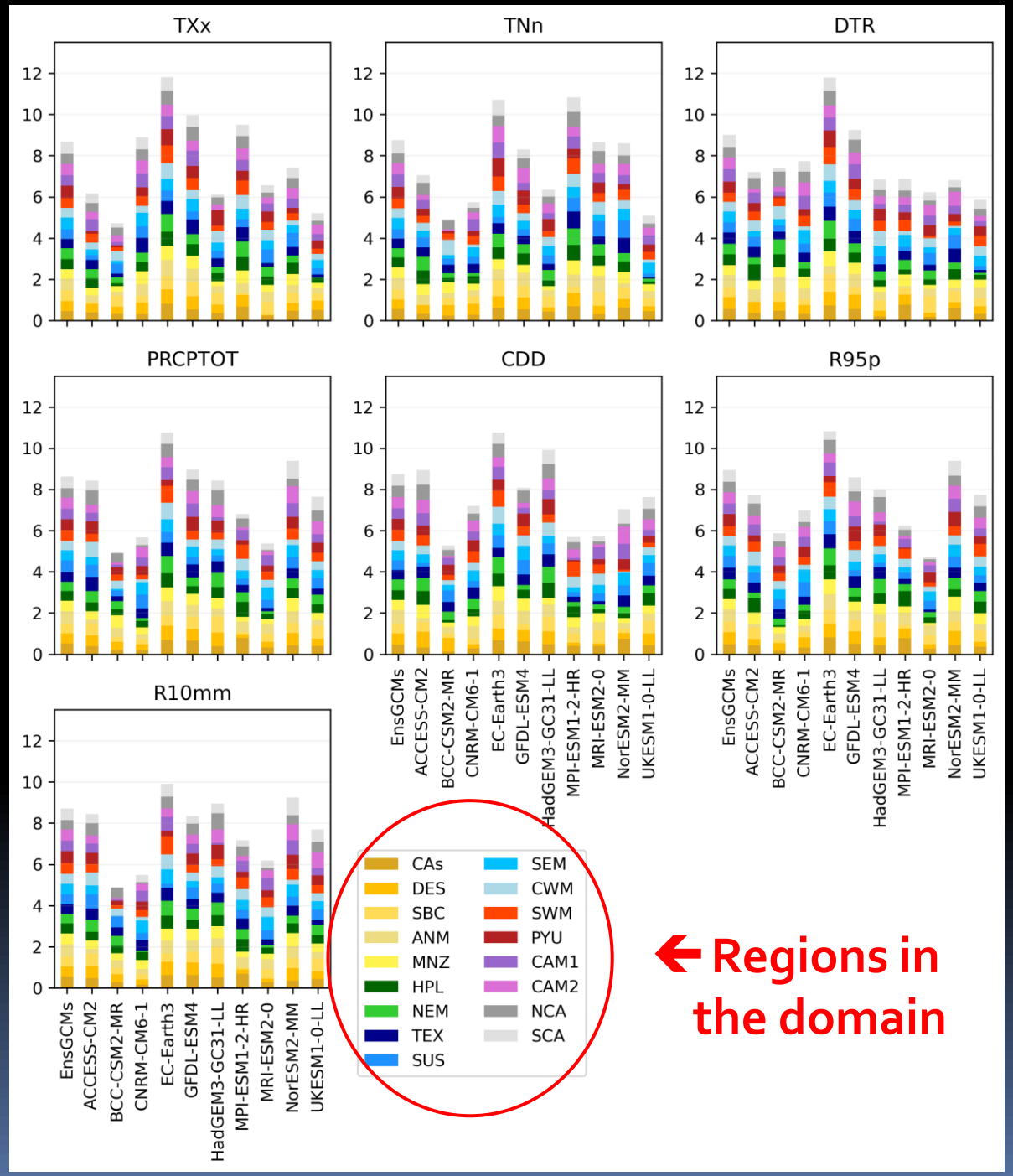
TSS = 1 Best

Model Ranking Metric (RM) for each ECI





We select the largest RM in each region to obtain the final ranking for each ECI.
For example, in the Californias (CAs), EC-Earth has the largest ranking (0.8) then then its model ranking is 1 in the right figure. This is done for each ECI and then, an average is obtained.



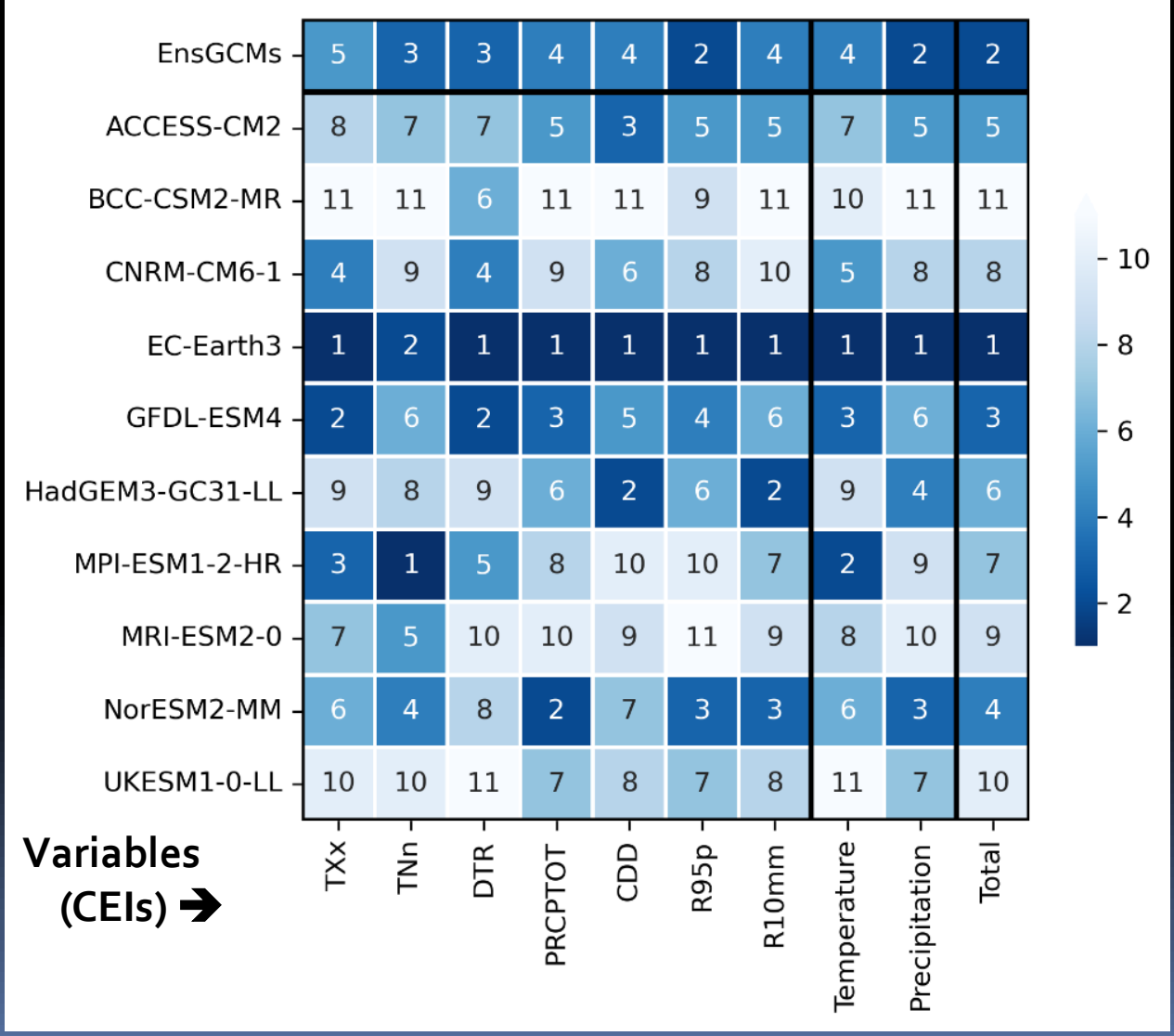
Cumulative Model Ranking for each ECI:

➔ The higher the columna, the better

➔ The stack plot is visually simpler than a table

➔ Regions in the domain

Ranking of GCMs for each CEI according to regional evaluation



Four Metrics:

- Bias, spatial Correl.
- Taylor Skill Score
- Relative Variability (CV model
- / CV Ref).

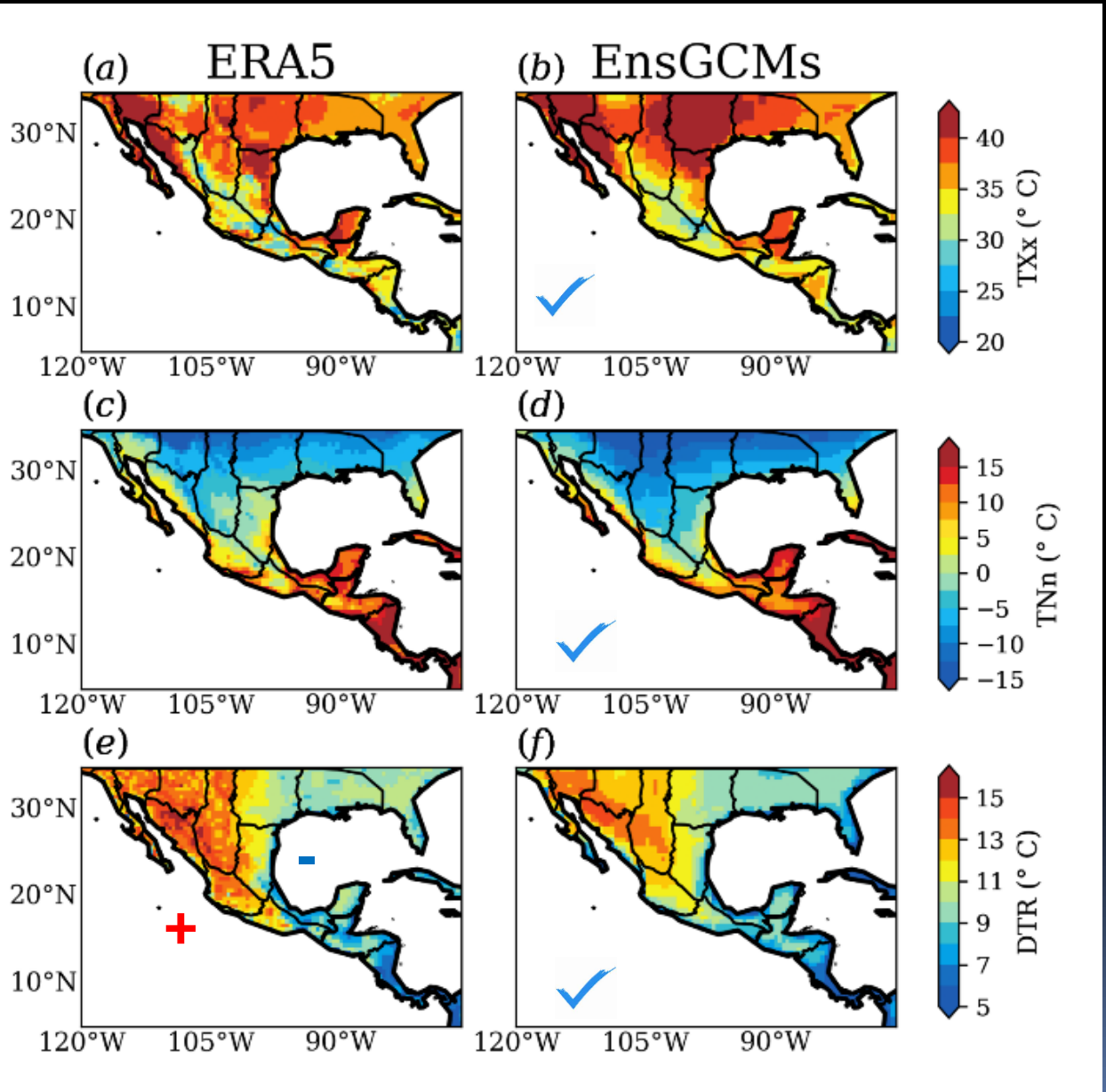
Best performances:

1. EC-Earth3
2. **Ensemble (EnsGCMs)**
3. GFDL-ESM4,
4. NorESM2
5. ACCESS-CM2
6. HadGEM3-GC31-LL

RESULTS: Climate Extreme Indices

Observed vs median ensemble of GCMs (1981-2010)

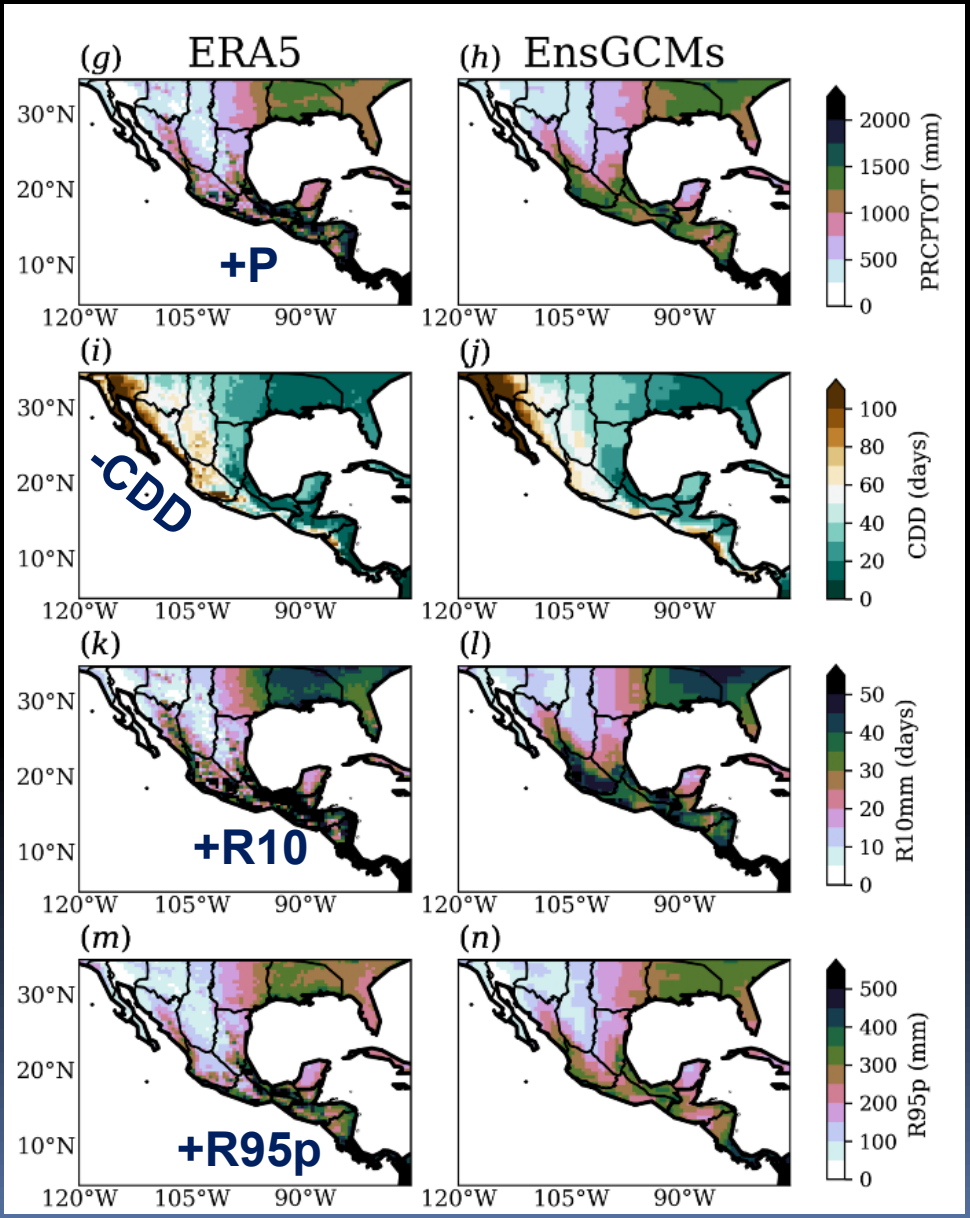
Extreme Tmax, Extreme Tmin and DTR



Historical climate extremes (1981-2010)

- **TXx** > **35°C** bounded by mountain
- **TNn** > **20°C** in costal areas and DES, CAs.
- **Higher DTR** in NW Mex y SW USA, regions with more extreme climates

Precip, R95p, and consecutive dry days (CDD)

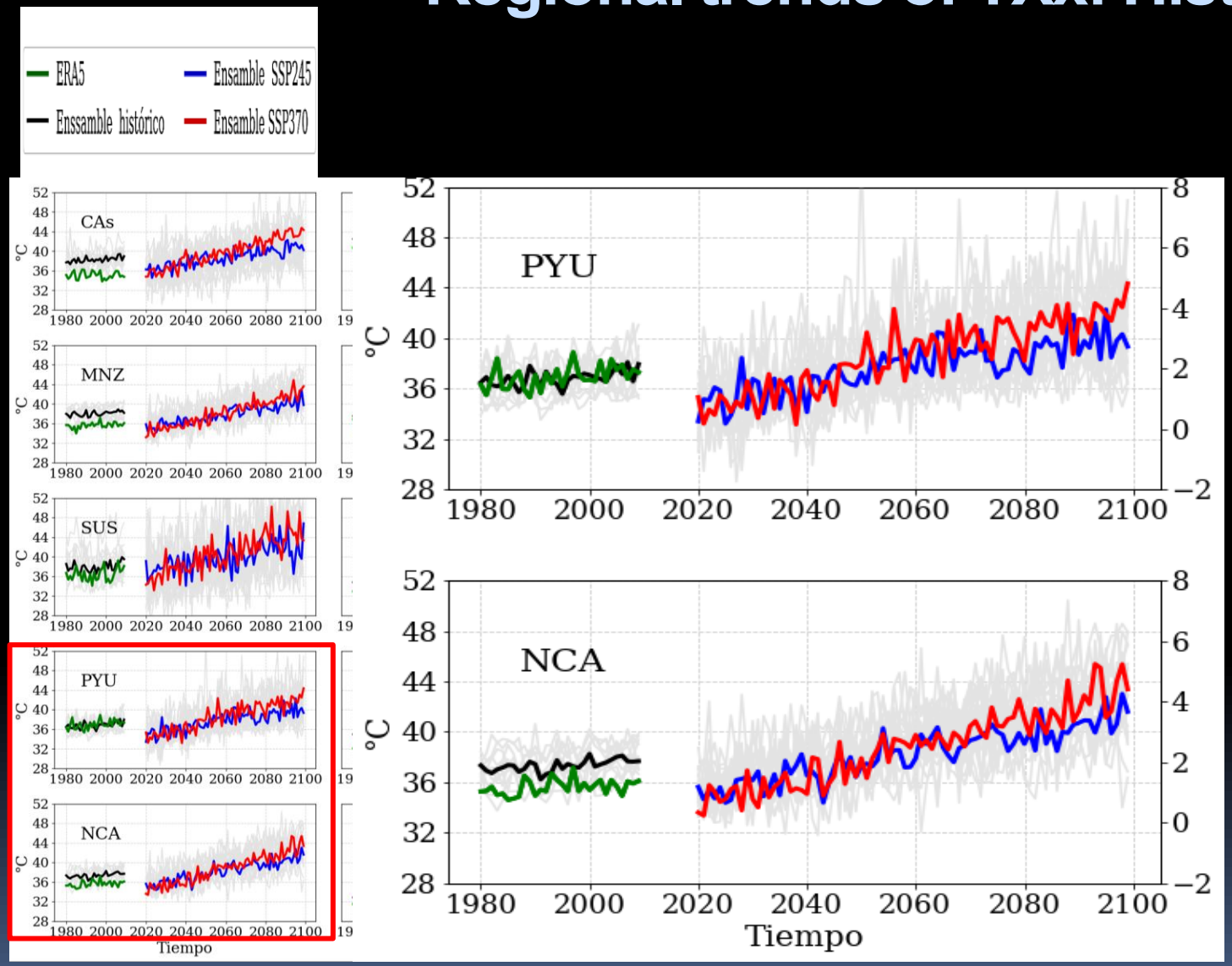


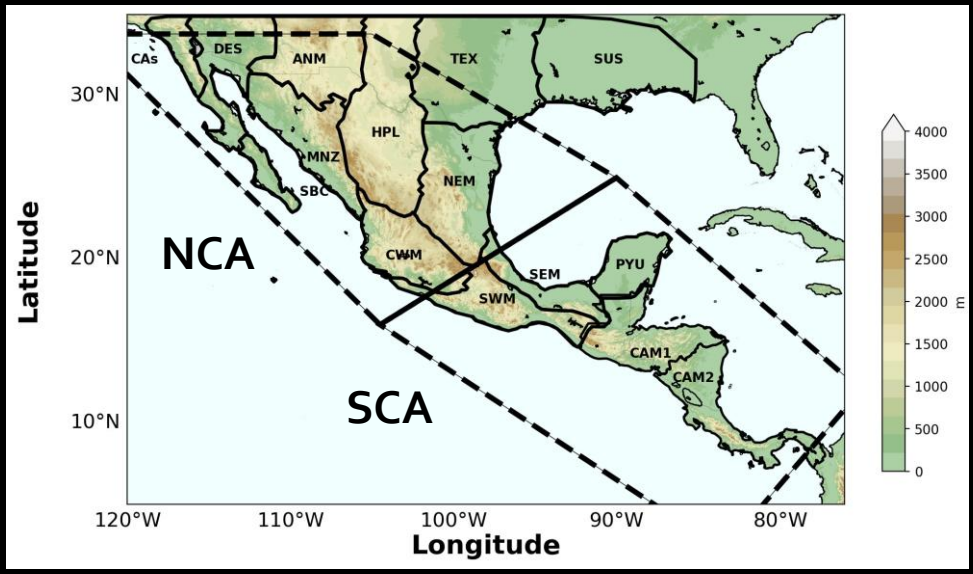
Historical climate extremes (1981-2010)

Historical and future trends

1981-2010 ➔ ERA5 and EnsGCMs
Future Scenarios: SSP2-4.5 and SSP3-7.0

Regional trends of TXx: Hist. and future projections





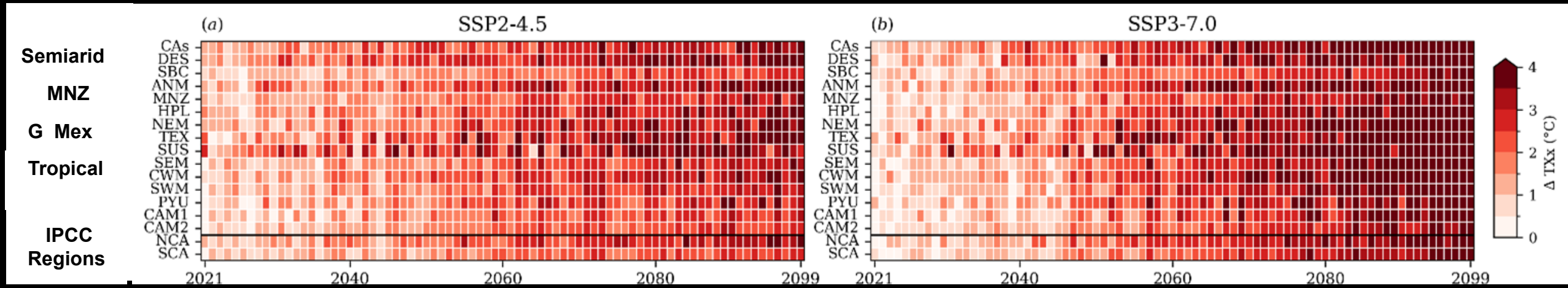
Future projections

(SSP2-4.5 y SSP3-7.0)

Regional changes of climate extreme indices at annual scale

(2021-2040, 2041-2060 y 2080-2099)

Regional changes in TXx (°C)
21st century: SSP2-4.5 y SSP3-7.0



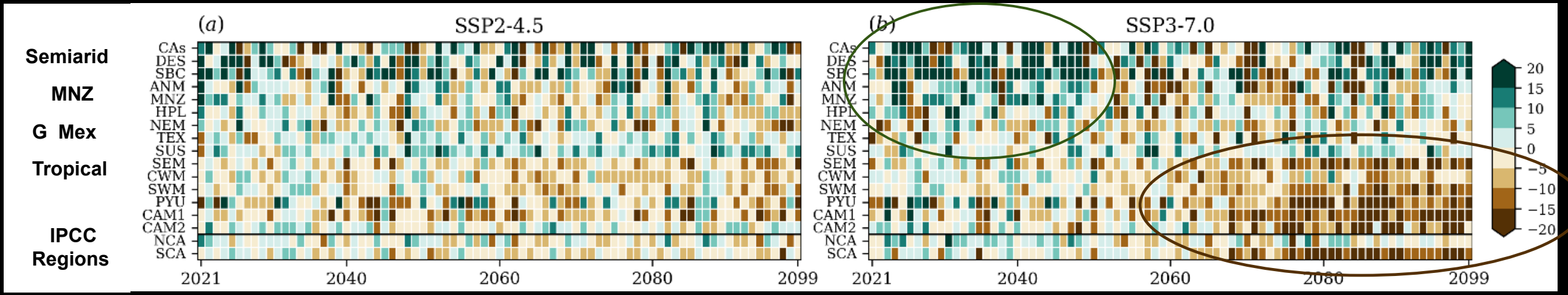
Early warming: Californias (Cas)

Desert (DES)

Arizona New Mexico (ANM)

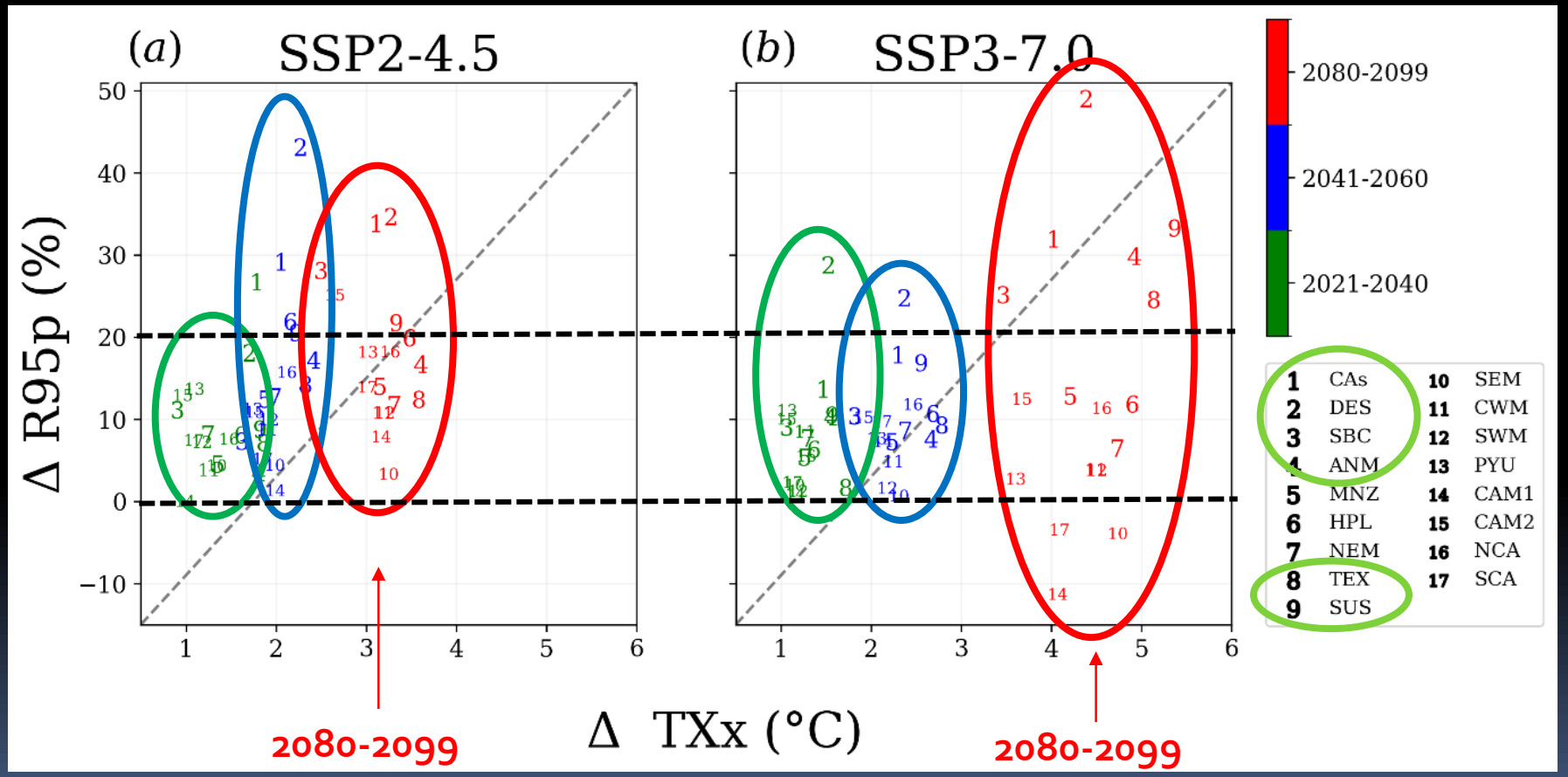
Texas (TEX) and Southeast US (SUS)

Regional changes in PRCPTOT %
21st century: SSP2-4.5 y SSP3-7.0



- Increased interannual variations
- Increase in subtropical zones
- Decrease in tropical zones

Regional sensitivity of changes in extreme precipitation (R95p) to changes in TXx



- **By the end of the century**, under the high-emissions scenario (SSP3-7.0), **TXx increases > 3.5°C**
- **R95p shows increases in subtropical regions** (> **10% and 20%**), while tropical regions exhibit **smaller changes** or **even decreases**

Scientific Questions…

- Which temperature and precipitation extreme indices show significant trends **in regions of Mexico**, the southern United States, and Central America during 1981–2010?

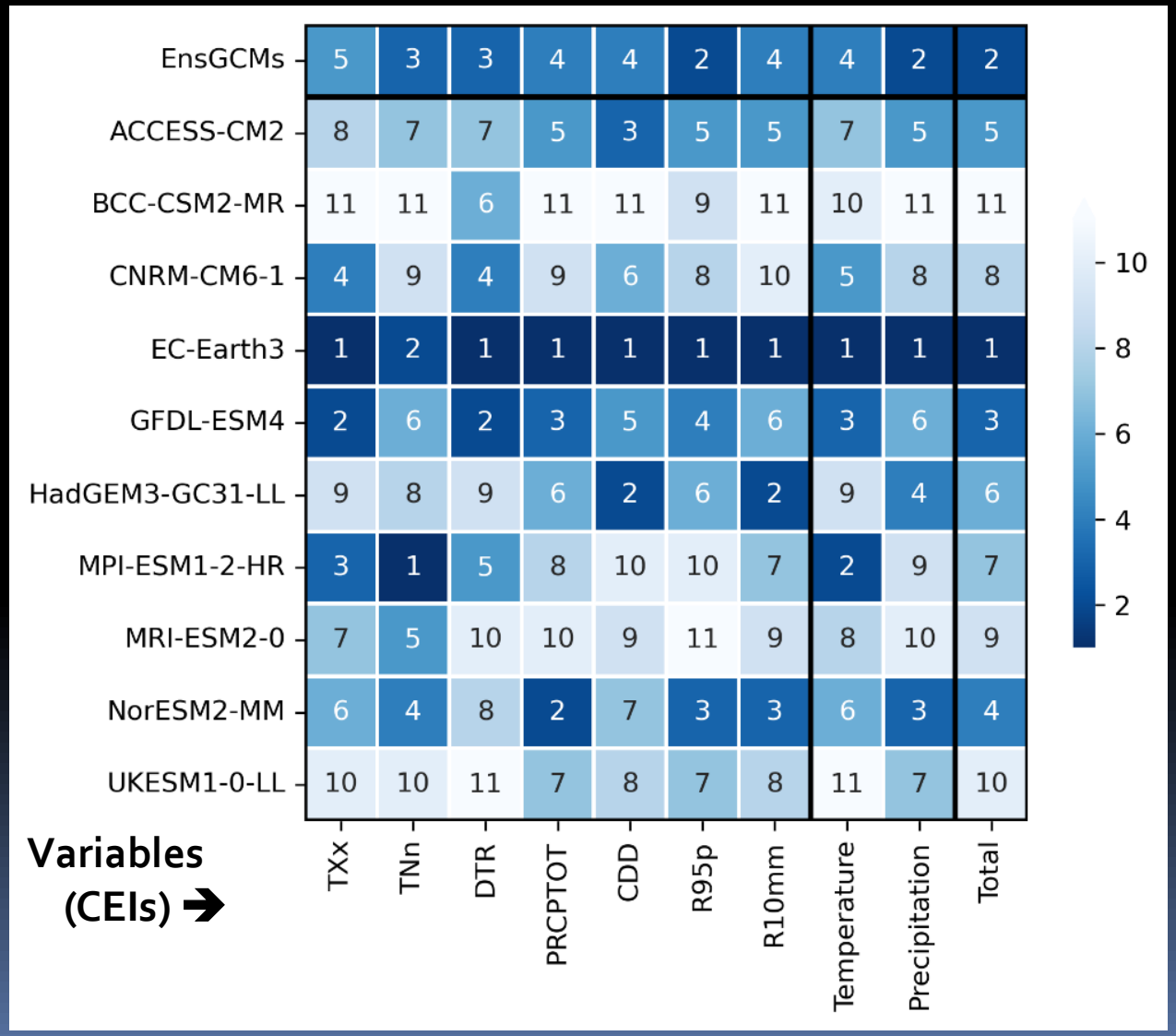
  ➔ Yes, temperature indices in all regions; precipitation varied by region

- Are these trends and mean conditions well represented by CMIP6 models?

  ➔ Yes, but with some biases

  ➔ We selected the top 5 models, with EC-Earth3 as the best in the region

Ranking of GCMs for each CEI according to regional evaluation



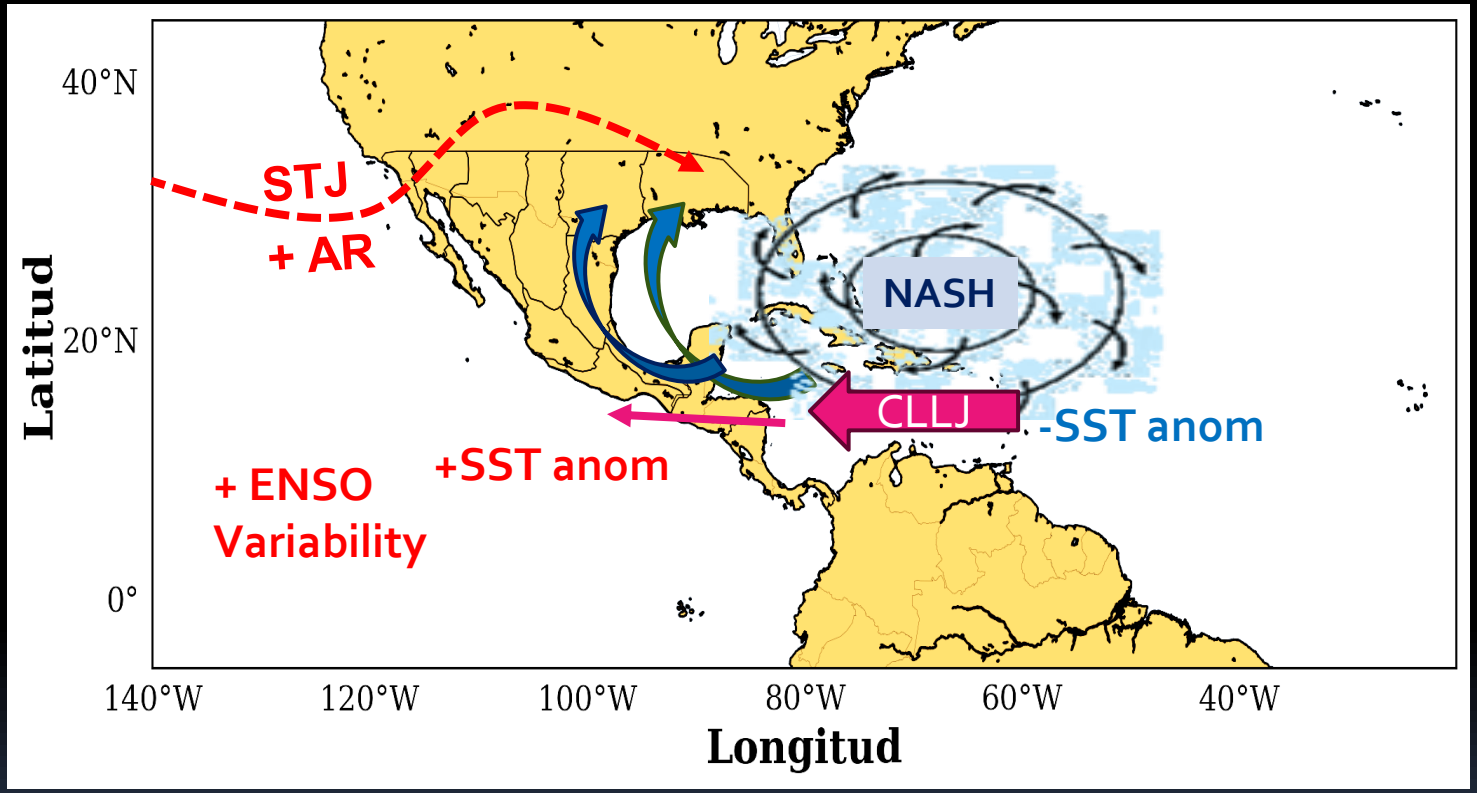
Four Metrics:

- Bias, spatial Correl.
- Taylor Skill Score
- Relative Variability (CV model /CV Ref).

Best performances:

1. EC-Earth3
2. **Ensemble (EnsGCMs)**
3. GFDL-ESM4,
4. ACCESS-CM2
5. CNRM-CM6-1
6. NorESM2

Discussion on climate drivers



- **Stronger NASH** could favor mositure advection from the GoM to the continent *(Song et al., 2018; Zhou et al., 2021).*
- Different CMIP5-6 suggest an **intensified CLLJ** in the future, which could partially explain the reduced precipitation índices in the Tropical regions (Bustos Usta & Torres Parra, 2023; Torres-Alavez et al., 2021).
- **SST gradient between Atlantic (-) and Pacific (+) (**Fuentes-Franco et al., 2015)
- More ENSO variability (e.g., Cai et al., 2021)
- Effect of cloudiness and radiation on the position and intensity of the Hadley Cell. ➔ higher clouds in the ITCZ but less horizontal extension (Su et al., 2021).

Paper to be submitted soon to Climatic Change

Thanks!

https://usuario.cicese.mx/~tcavazos/index.php
tcavazos@cicese.mx