Evaluation of the CMIP6 multimodel ensemble for climate extreme indices

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1. Introduction

- ✓ Extreme climate and weather events are generally multifaceted phenomena with huge impacts on human society and the ecosystem.
- ✓ Releasing the new generation of global climate models (GCMs) participating in the Coupled Model Intercomparison Project Phase 6 (CMIP6)
- ✓ One of the scientific focuses of the CMIP6 experiment is to assess changes in climate extremes for the past and future periods and to understand associated physical processes.
- ✓ Evaluation of CMIP6 model performance for climate extremes is important.
- ✓ One approach is to use the climate extremes indices defined by the ETCCDI. The ETCCDI indices represent relatively frequent extreme meteorological events in a given year or month, so it is relatively easy to understand their changes
- ✓ The other approach is to analyze changes in more extreme climate statistics based on the extreme value theory, using GEV analysis.

This study evaluates the performances of CMIP6 models in terms of the 27 climate extremes indices defined by the ETCCDI in comparison to those of CMIP5 models (Sillmann et al. 2013)

2. Data and Methodology

Data

Reference data sets

- HadEX3 (pre-released version) : global land-based climate extreme datasets (1.875°lon × 1.25°lat)
- ERA-5 (0.25°lon × 0.25°lat) / ERA-40 (2.5°lon × 2.5°lat) / NCEP-NCAR (1.875°lon × 1.9°lat) / NCEP-DOE (1.875°lon × 1.9°lat)

GCMs

- CMIP6 : 25 models / historical experiment (anthropogenic plus natural forcing)
- CMIP5 : 35 models / historical experiment (anthropogenic plus natural forcing)
- One (typically the first) ensemble member of each model

Analysis period : 1981-2000

Climate extreme indices

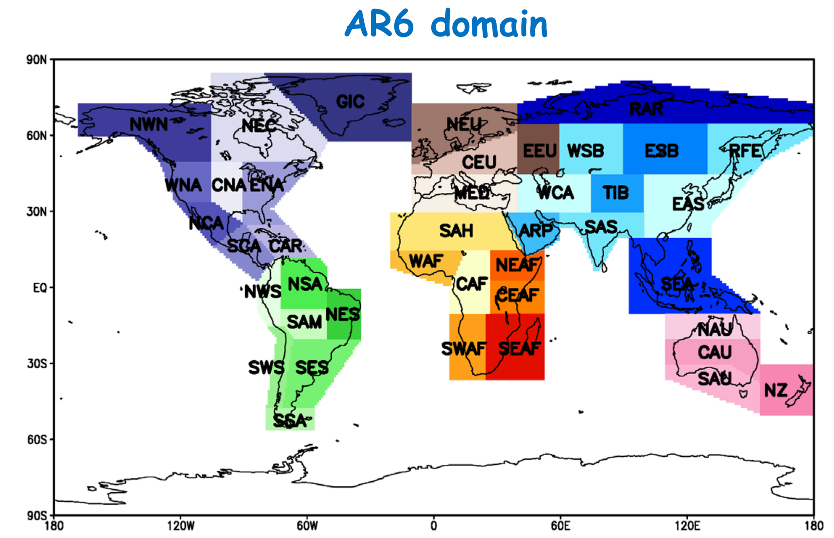
: 27 ETCCDI climate extreme indices (16 temperature and 11 precipitation) representing intensity, frequency and duration

Data processing

1) Calculate the 27 climate extreme indices on original grid of each model
2) Interpolate climate extreme indices onto the same grids (1°×1°) and then take area-average for global land and 41 sub-regions
   * ERA-5 : first interpolate daily temperature and precipitation data at 30km resolution into 1°×1° grid and then calculate climate extreme indices due to reduce the difference in spatial scales from CMIP6 models (1~2°)

Regional Domain

AR6 domain



Model performance metric (Sillmann et al., 2013)

- Metric is based on the RMSEs of model climatology pattern

$$RMSE_{XY} = \sqrt{< (X - Y)^2 >}$$

X : model climatology of an index
Y : reanalysis climatology of an index
<> : Spatial averaging over a domain

- **Relative magnitude of spatially averaged RMSE** for each indices and for each model

$$RMSE'xy = \frac{RMSE_{XY} - RMSE_{median}}{RMSE_{median}}$$

$RMSE_{median}$: the median of RMSE for all models

- **Absolute magnitude of errors** in the multimodel ensemble with respect to the reanalyses

$$RMSE_{median,std} = RMSE_{median} / \sqrt{< (Y - < Y >)^2 >}$$

Y : reanalysis climatology of an index
<> : Spatial averaging over a domain

GEV analysis

- Cumulative den si ty func tion (CDF) of the GEV distribution for variable x is:

$$F(x; \mu, \sigma, \xi) = \begin{cases} exp\left[-exp\left\{-\frac{x-\mu}{\sigma}\right\}\right], & \xi = 0 \\ exp\left[-\left\{1+\xi\frac{x-\mu}{\sigma}\right\}^{-\xi^{-1}}\right], & \xi \neq 0, \quad 1+\xi\frac{x-\mu}{\sigma} > 0 \end{cases}$$

CDF of GEV distribution
μ : location parameter
σ : scale parameter
ξ : shape parameter

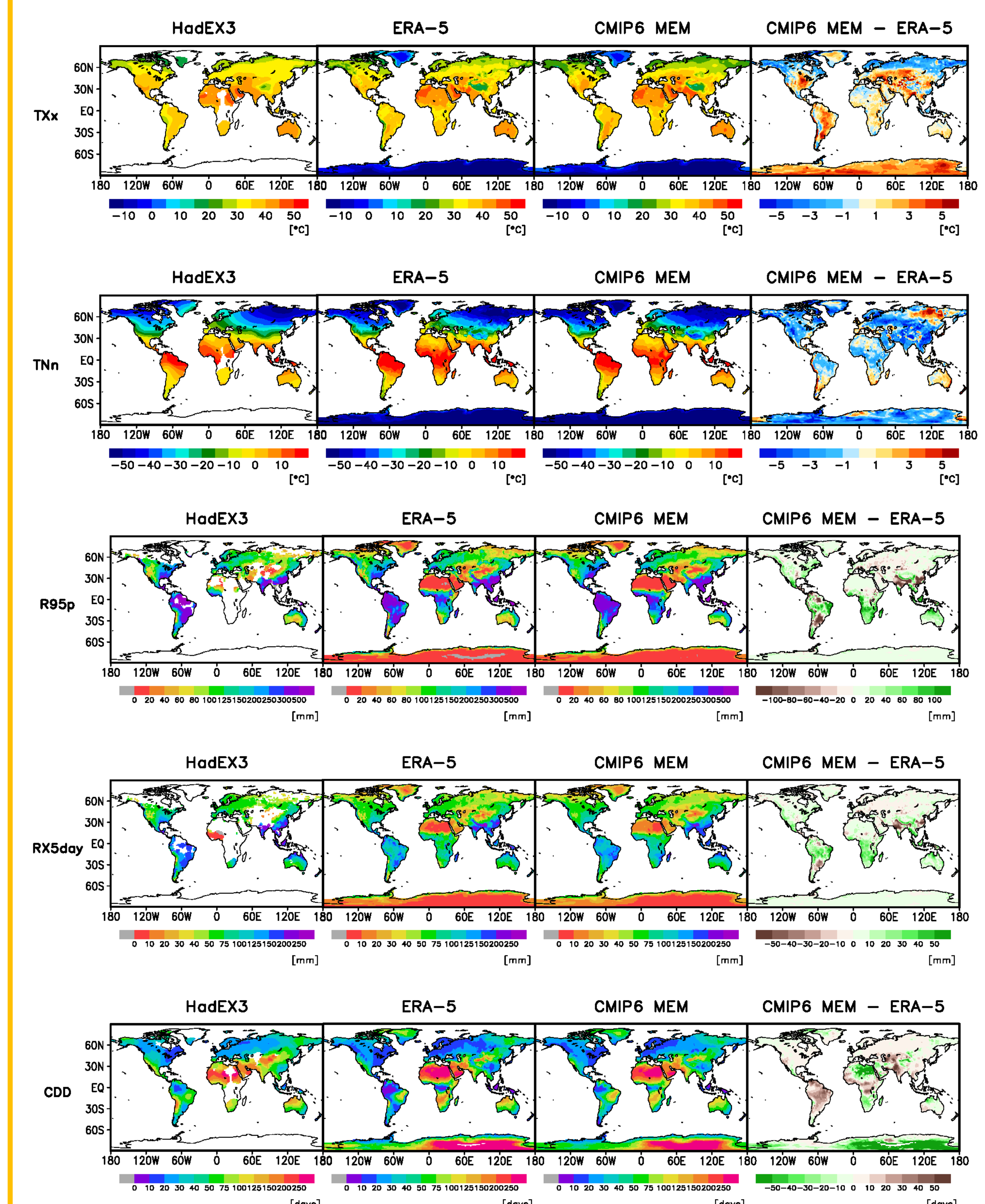
- Quantile function of GEV is derived by inverting a CDF for a given probability (p)

$$X_p(t) = \begin{cases} \mu_t - \sigma \ln[-\ln(p)], & \xi_t = 0, \\ \mu_t - \frac{\sigma}{\xi} \ln\left[1 - (-\ln(p))^{-\xi}\right], & \xi_t \neq 0. \end{cases}$$

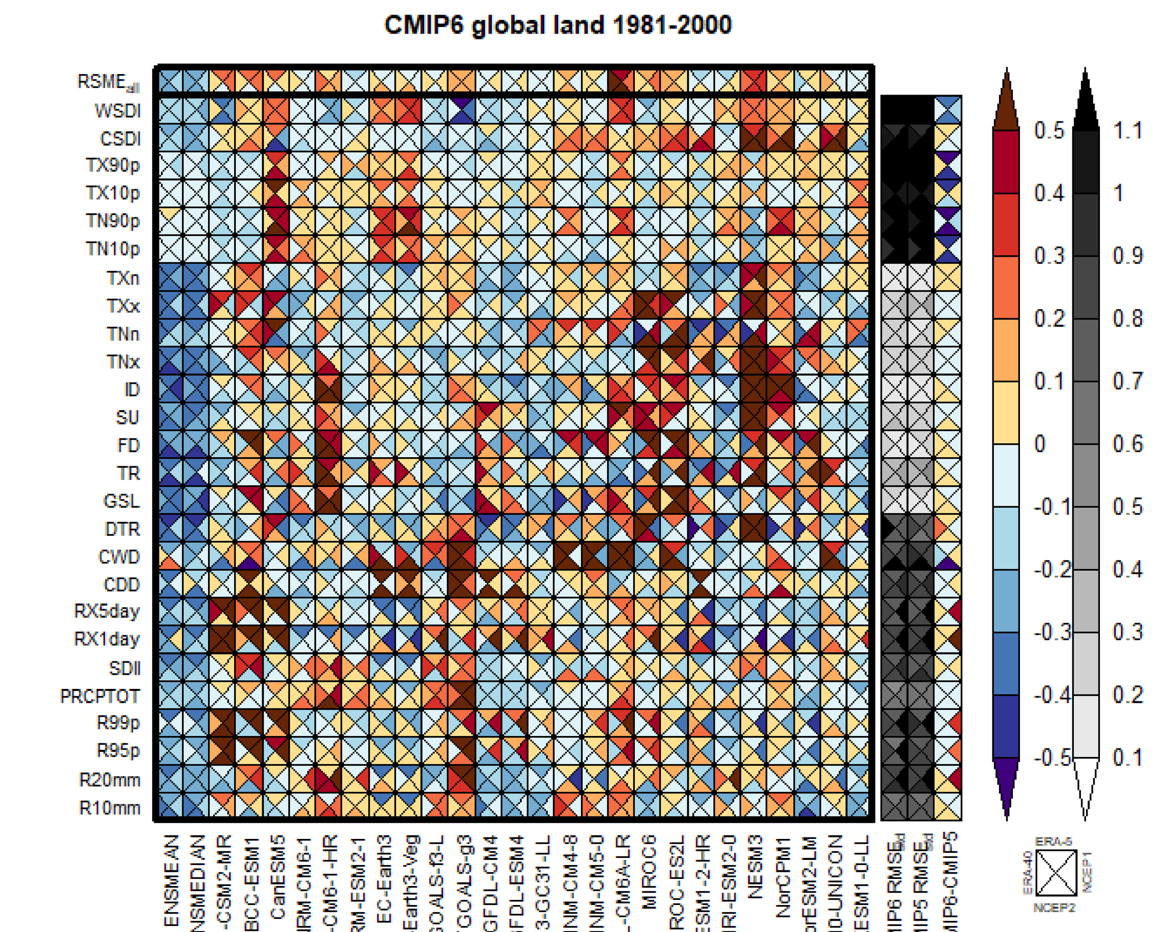
$20RV(t) = X_{0.95}(t)$
- **1st term** : location parameter (**mean intensity**)
- **2nd term** : function of scale and shape parameters (**interannual variability**)

3. Result

Spatial distribution of climatology

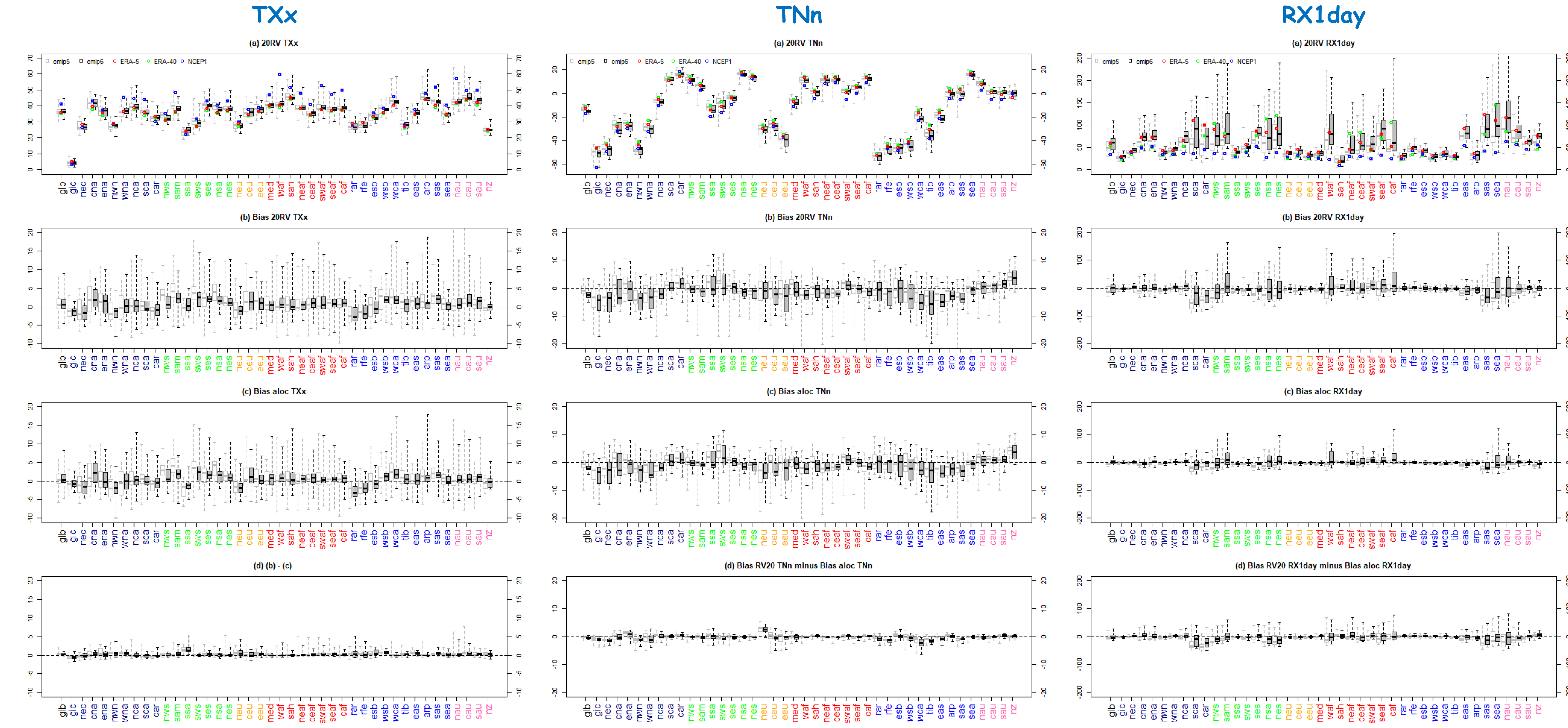


Portrait diagram



- CMIP6 models simulate lower TXx over northern high latitude and higher over eastern USA, west Asia, and South America
- TNn is colder in CMIP6 models across the global land except for northeastern Eurasia and southern mid-latitudes.
- For extreme precipitation events(R95p and RX5day), there are wet biases over southern Africa, central South America, and northern Australia.
- CMIP6 models overestimate Consecutive dry days (CDD) over South America and underestimate CDD over Sahara region.
- **CNRM-ESM2-0 shows the best performance** followed by **Met Office models (HadGEM3-GC31-LL and UKESM1-0-LL)**, MPI-ESM1-2-HR, CNRM–CM 6 -1, GFDL-CM4 and GFDL-ESM4
- Temperature extremes : **CMIP6 models has overall improved (TXx, TNx and SU, CSDI and WSDI).**
- Precipitation extremes : **CMIP6 models has some improved (PRCPTOT, R99p, R95p and CDD)**

20-year return level of annual maxima indices



- CMIP6 models generally able to capture the observed global and regional patterns of annual maxima indices
- **Bias of extreme precipitation intensity for CMIP6 are reduced over across regions**
- TXx : cold bias over northern high latitudes region and warm bias over south America and mid-latitude Asia
- TNn : cold bias over northern high latitudes area and mid-latitude Asian area

} **Bias contribution : mean intensity**

- RX1day : dry bias over the tropics and the subtropical rain band area - **Bias contribution : mean intensity** and **interannual variability**

4. Conclusions

- This study documents the performances of the GCMs participating in CMIP6 in terms of climate extremes compared with those of CMIP5 models.
- The model-simulated values for the climate extremes indices defined by the ETCCDI are compared to HadEX3 observations and four reanalyses.
- 20-year return values of the annual maxima temperature and precipitation are also evaluated for the global land and 41 sub-regions

- CMIP6 models capture the observed climatology pattern of temperature and precipitation indices well, overall similar to CMIP5 models
- Warm extremes : Colder conditions over the Americas
- Cold extremes : Colder biases over high latitude areas
- Precipitation extremes : More strong extreme precipitation, reducing dry biases over the tropical and subtropical rain band regions
- Systematic biases remain in CMIP6 models in cold extremes and precipitation extremes
- GEV analysis indicates that mean intensity is important for the bias in temperature extremes whereas interannual variability is also important for the bias in precipitation extremes.

- Influence of higher spatial resolutions and improved physical processes will be further examined.

Kim, Y.-H., S.-K. Min, X. Zhang, J. Sillmann, and M. Sandstad, 2020: Evaluation of the CMIP6 multi-model ensemble for climate extreme indices. *submitted*