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Crossbreeding CMIP6 Earth System Model Features with an Emulator

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Improving future climate change projections with the MESMER emulator

What? Improving the sampling of the temperature projection phase space compared to the newly available Coupled Model Intercomparison Project phase six (CMIP6) ensemble.
Why? These projections serve as basis for global and regional assessments of future climate change. However, the projection phase space is only sparsely sampled by the CMIP6 ensemble (Earth System Models (ESMs) = computationally expensive -> limited number of runs available) + agreement with observations is not taken into account.
How? With the MESMER emulator.

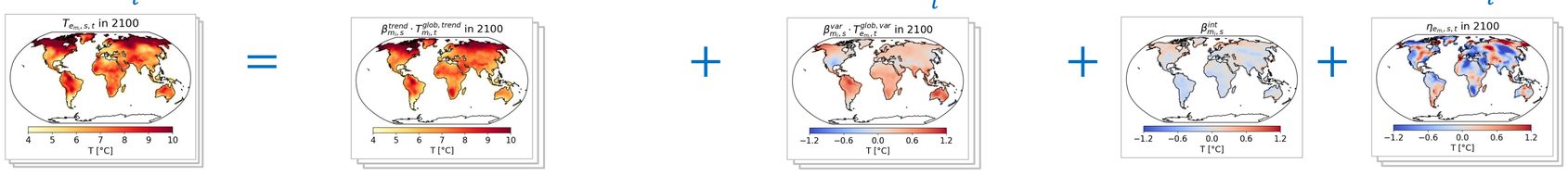
(Beusch et al., 2020b)

MESMER mimics ESM-specific large initial-condition ensembles at a negligible computational cost

MESMER = **M**odular **E**arth **S**ystem **M**odel **E**mulator with spatially **R**esolved output
Emulated yearly land temperature T at each grid point s and time t is an ESM-specific e_{m_i} linear function of the current global mean temperature T^{glob} ($= T^{glob,trend} + T^{glob,var}$) and a spatio-temporally correlated noise term η

Smooth trend | AR(p) process | AR(1) process with spatially correlated innovations

$$T_{e_{m_i},s,t} = \beta^{trend}_{m_i,s} \cdot T^{glob,trend}_{m_i,t} + \beta^{var}_{m_i,s} \cdot T^{glob,var}_{e_{m_i},t} + \beta^{int}_{m_i,s} + \eta_{e_{m_i},s,t}$$



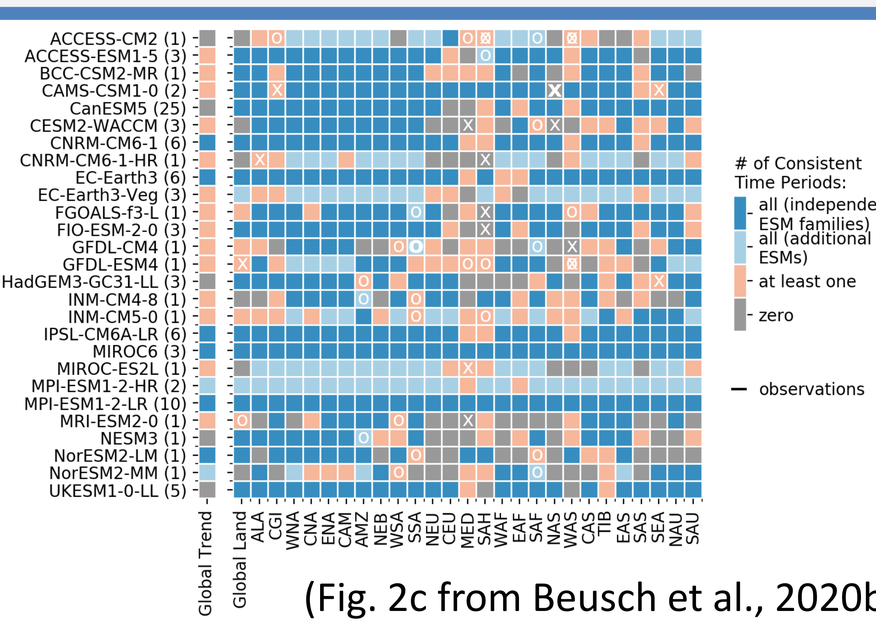
≈ Large multi-model, initial-condition ensemble = raw supersenemble

(Beusch et al., 2020a)

ESM evaluation reveals no direct relationship for ESMs' performances at global and regional scales

Bridging the gap between ESM realizations and observations with emulations

1. Train emulator on full time period (1870 – 2100) with all ESM initial-condition ensemble members
2. Create 1'000 emulations (EMUs) per ESM
3. Compute feature of interest for each EMU, each ESM run, and each observational product individually in several time windows → if 2.5 – 97.5 percentile of EMUs contains ESM runs + observations, ESM + its EMUs are considered consistent with observations for this time window:
   - Global-scale feature: T^{glob}_t linear trends in time
   - Regional-scale feature: regionally-averaged β^{trend}_s



(Fig. 2c from Beusch et al., 2020b)

Crossbreeding as a tool to avoid loss of information in observationally-constrained ESM ensembles

In Beusch et al. (2020b), we propose to «crossbreed» ESMs to **retain the full suite of ESM features consistent with observations** at global and regional scales:

$$T_{e_{m_{ij}},s,t} = \beta^{trend}_{m_i,s} \cdot T^{glob,trend}_{m_j,t} + \beta^{var}_{m_i,s} \cdot T^{glob,var}_{e_{m_i},t} + \beta^{int}_{m_i,s} + \eta_{e_{m_i},s,t}$$

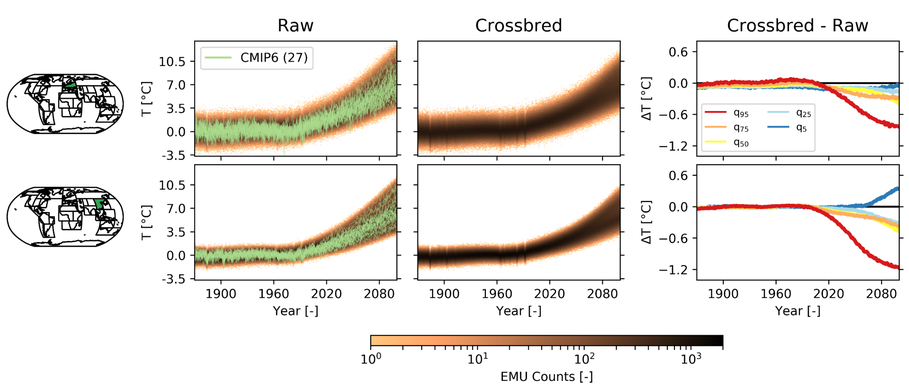
i: index through ESMs consistent with observations in terms of regionally-averaged $\beta^{trend}_{m_i,s}$
j: index through ESMs consistent with observations in terms of $T^{glob}_{m_j,t}$ linear trends in time

≈ Large observationally-constrained, regionally-optimized, recombined multi-model, initial-condition ensemble = crossbred superensemble

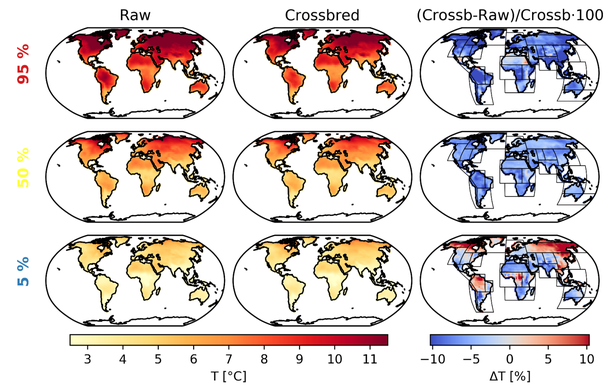
Results are spatially diverse and inter-ESM uncertainty remains large

Conservative removal approach: **grey ESMs excluded**, i.e. the ones never consistent with observations (for details + «best estimate» approach see Beusch et al., 2020b)

Regionally-averaged temperature time series for Central Europe and East Asia for the CMIP6 ensemble, the raw superensemble, and the crossbred superensembles



Different quantiles in 2095 for the raw and the crossbred superensembles



For more information and to cite our work, please use:

Beusch, L., Gudmundsson, L., and Seneviratne, S. I. (2020a): Emulating Earth system model temperatures with MESMER: from global mean temperature trajectories to grid-point-level realizations on land, Earth Syst. Dynam., 11, 139–159, 10.5194/esd-11-139-2020.

Beusch, L., Gudmundsson, L., and Seneviratne, S. I. (2020b): Crossbreeding CMIP6 Earth System Models with an Emulator for Regionally-optimized Land Temperature Projections, GRL, early online release, 10.1029/2019GL086812.