Global changes in extreme events from multi-model GCM ensembles: Regional and seasonal dimension

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Abstract

We systematically analyze the complete IPCC AR4 ensemble of GCM simulations with respect to changes in extreme event characteristics at the end of the 21st century (2081-2100) compared to present-day (1980-1999) conditions [1]. This complements previous studies [2] by investigating a more comprehensive database and considering seasonal changes beside the annual time scale in the analysis.

General findings:

- high agreement for increased warm days and heatwaves
  - definition of heatwaves remains an issue
- generally more ambiguous changes in precipitation and dryness extremes
  - consistent changes: wetting in Northern high latitudes, drying in the Mediterranean
  - dryness change patterns depend on index (e.g. consecutive dry days or soil moisture anomalies)
- scaling analysis of different contributions to temperature extreme changes
  - changes well related to changes in the seasonal cycle
  - changes in extremes at times much larger than global warming (compare 2°C-warming target)

To date, a similar analysis of AR5 simulations has not been possible because of the limited number of available simulations.

Indices

Temperature indices

- **%WD** (warm days): fraction of days per year or season, at which $T_{\max} > q90$, where $q90$ gives the climatological 90%-ile of $T_{\max}$ for that day
- **%CD** (cold days): fraction of days per year or season, at which $T_{\max} < q10$, where $q10$ gives the climatological 10%-ile of $T_{\max}$ for that day
- **$T_{\max}$ >30°C** (hot days): Fraction of days with $T_{\max}$ >30°C are calculated for each 20-year period
- **HWDImax (HWDImean)** (maximum/mean heatwave duration index): Maximum (mean) period length per year or season of at least 5 consecutive days, at which $T_{\max} >$ climatology+5K
- **WSDI** (warm spell duration index): fraction of days per year or season which belong to periods of at least 6 days at which consecutively $T_{\max} > q90$, where $q90$ gives the climatological 90%-ile of $T_{\max}$ for that day

Precipitation indices

- **Wet Day Intensity**: Average precipitation amount on wet days (pr $\geq$ 1mm) for each year or season
- **pr > $q95$**: Fraction of days with pr > $q95$ are calculated for each 20-year period, where $q95$ gives the climatological 95%-quantile of wet day precipitation from the reference period
- **pr > 10mm** (heavy precipitation): Fraction of days with pr > 10mm per year or season

Dryness indices

- **CDD** (consecutive dry days): maximum period length per year or season of days without precipitation, that is pr < 1mm
- **SMA** (soil moisture anomalies): anomalies of soil moisture averaged at the seasonal and annual time scale

GCM data

For each of the AR4/CMIP3 GCMs, all runs which were available both in the 20C3M and the SRES-A2 experiments were used after some consistency checks.

Institution	Model	Resolution	Variables (No. of runs)
Bjerknes Centre for Climate Research	BCCR-BCM2.0	T63	pr, $T_{\max}$, $T_{\min}$
Canadian Centre for Climate Modeling and Analysis	CGCM3.1-T47	T47	pr (3), $T_{\max}$ (3), $T_{\min}$ (3), mrso (5)
Météo-France/Centre National de Recherches Météorologiques	CNRM-CM3	T63	pr, $T_{\max}$, $T_{\min}$
CSIRO Atmospheric Research	CSIRO Mk3.0	T63	pr, $T_{\max}$, $T_{\min}$
CSIRO Atmospheric Research	CSIRO Mk3.5	T63	pr, $T_{\max}$, $T_{\min}$
NOAA/Geophysical Fluid Dynamics Laboratory	GFDL-CM2.0	144×90	pr, $T_{\max}$, $T_{\min}$, mrso
NOAA/Geophysical Fluid Dynamics Laboratory	GFDL-CM2.1	144×90	pr, $T_{\max}$, $T_{\min}$, mrso
NASA Goddard Institute for Space Studies	GISS-ER	72×46	pr, $T_{\max}$, $T_{\min}$, mrso
Instituto Nazionale di Geofisica e Vulcanologia	INGV-ECHAM4	320×160	pr, $T_{\max}$, $T_{\min}$, mrso
Institute for Numerical Mathematics	INM-CM3.0	72×45	pr, mrso
Institute Pierre Simon Laplace	IPSL-CM4	96×72	pr, $T_{\max}$, $T_{\min}$, mrso
Center for Climate System Research (University of Tokyo)	MIROC3.2-medres	T42	pr (2), $T_{\max}$ (3), $T_{\min}$ (3), mrso (3)
Meteorological Institute of the University of Bonn	ECHO-G	T30	pr (3), $T_{\max}$ (3), $T_{\min}$ (3), mrso (3)
Max Planck Institute for Meteorology	ECHAM5/MPI-OM	T63	pr, $T_{\max}$, $T_{\min}$, mrso (3)
Meteorological Research Institute	MRI-CGCM2.3.2	T42	pr (5), $T_{\max}$ (5), $T_{\min}$ (5), mrso (5)
National Center for Atmospheric Research	CCSM3	T85	pr (3), mrso (3)
National Center for Atmospheric Research	PCM	T42	pr, mrso (4)
Hadley Centre for Climate Prediction and Research, Met Office	UKMO-HadCM3	T63	mrso
Hadley Centre for Climate Prediction and Research, Met Office	UKMO-HadGEM1	T63	mrso

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Temperature extremes

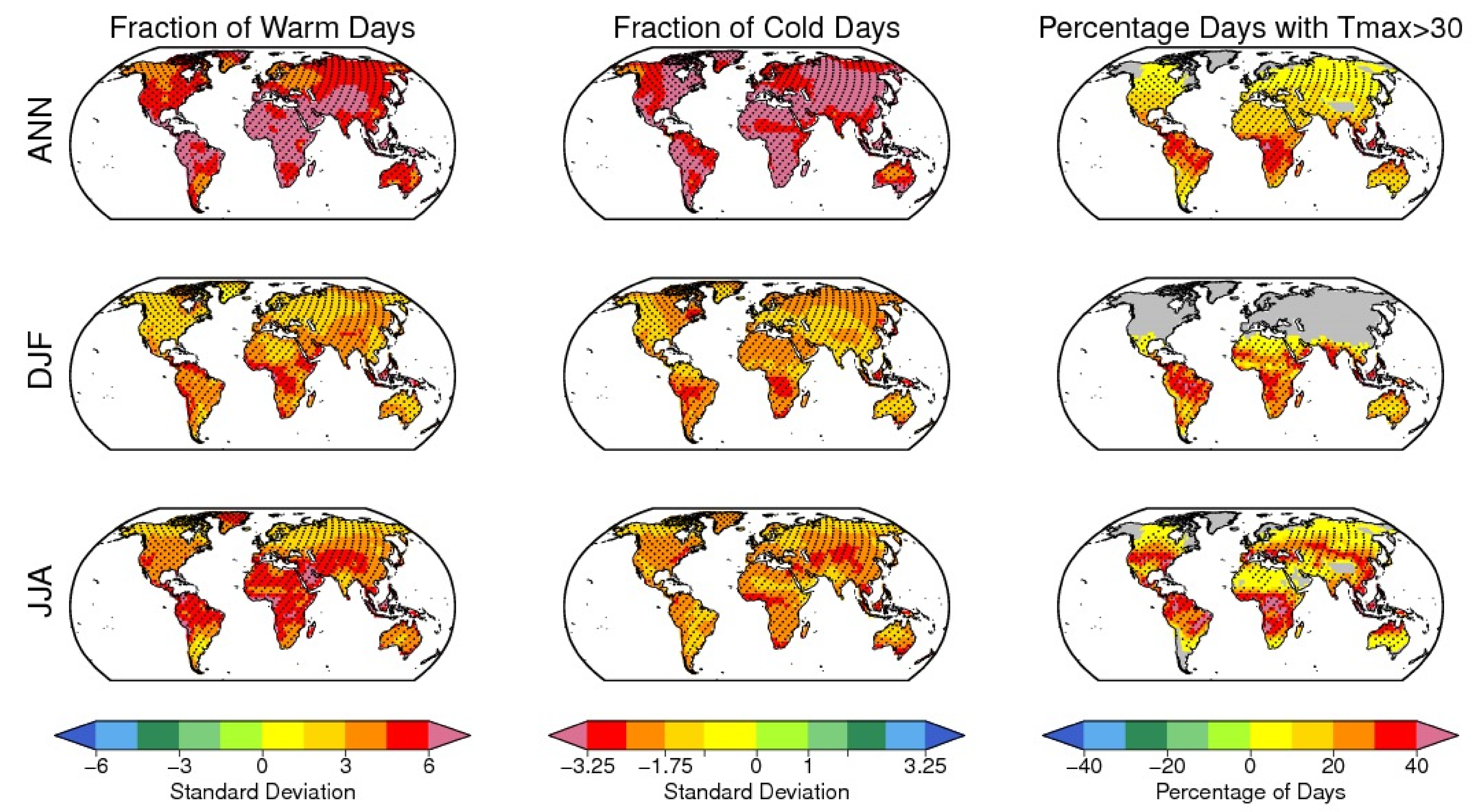

Fig. 1. Annual and seasonal changes (2081-2100 minus 1980-1999) of three indices for $T_{\max}$: Fraction of warm days, fraction of cold days and fraction of days with $T_{\max} > 30°C$.

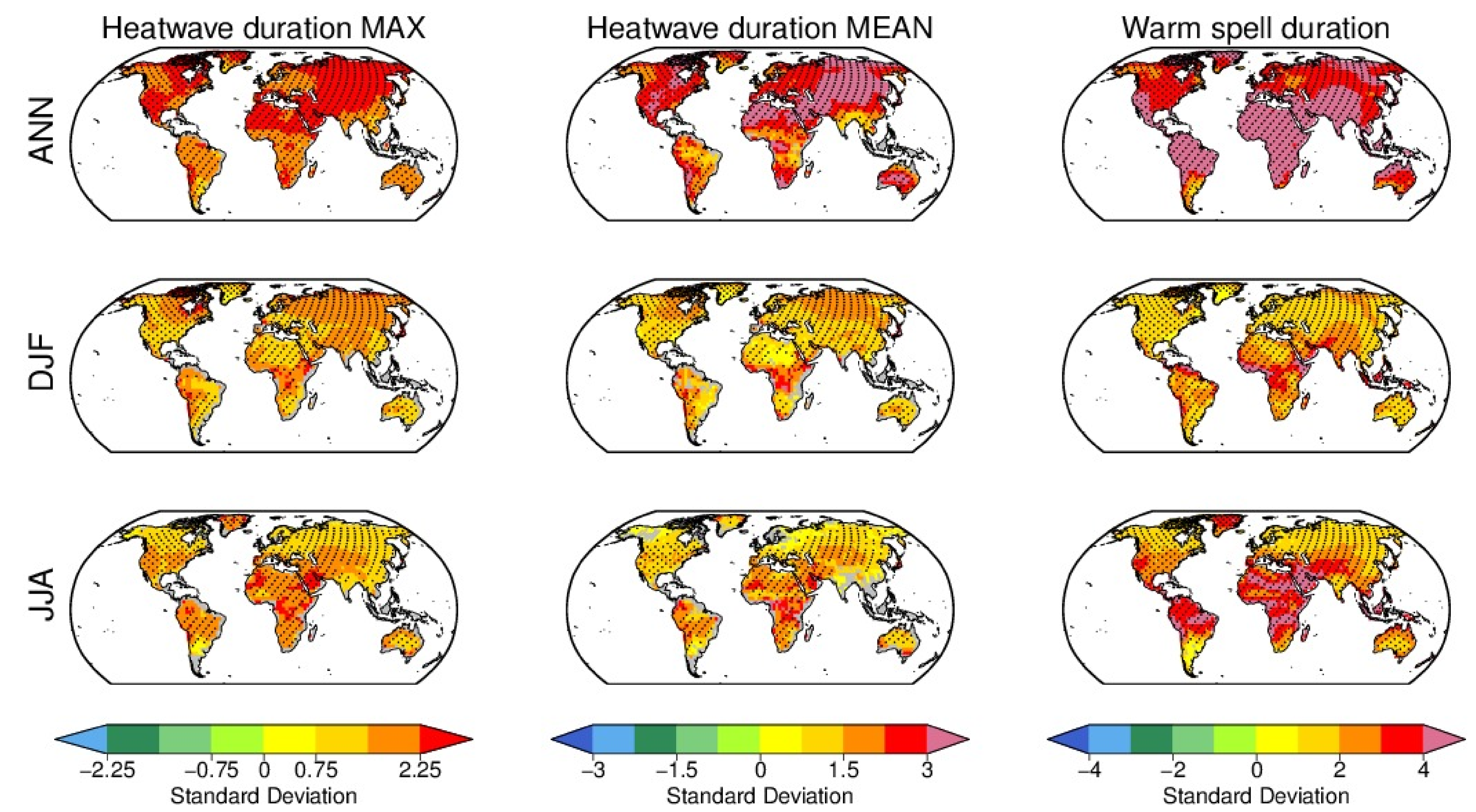

Fig. 2. Annual and seasonal changes (2081-2100 minus 1980-1999) of three heatwave indices: Maximum/mean heatwave duration indices (HWDImax/HWDImean) and the warm spell duration index (WSDI).

Precipitation extremes

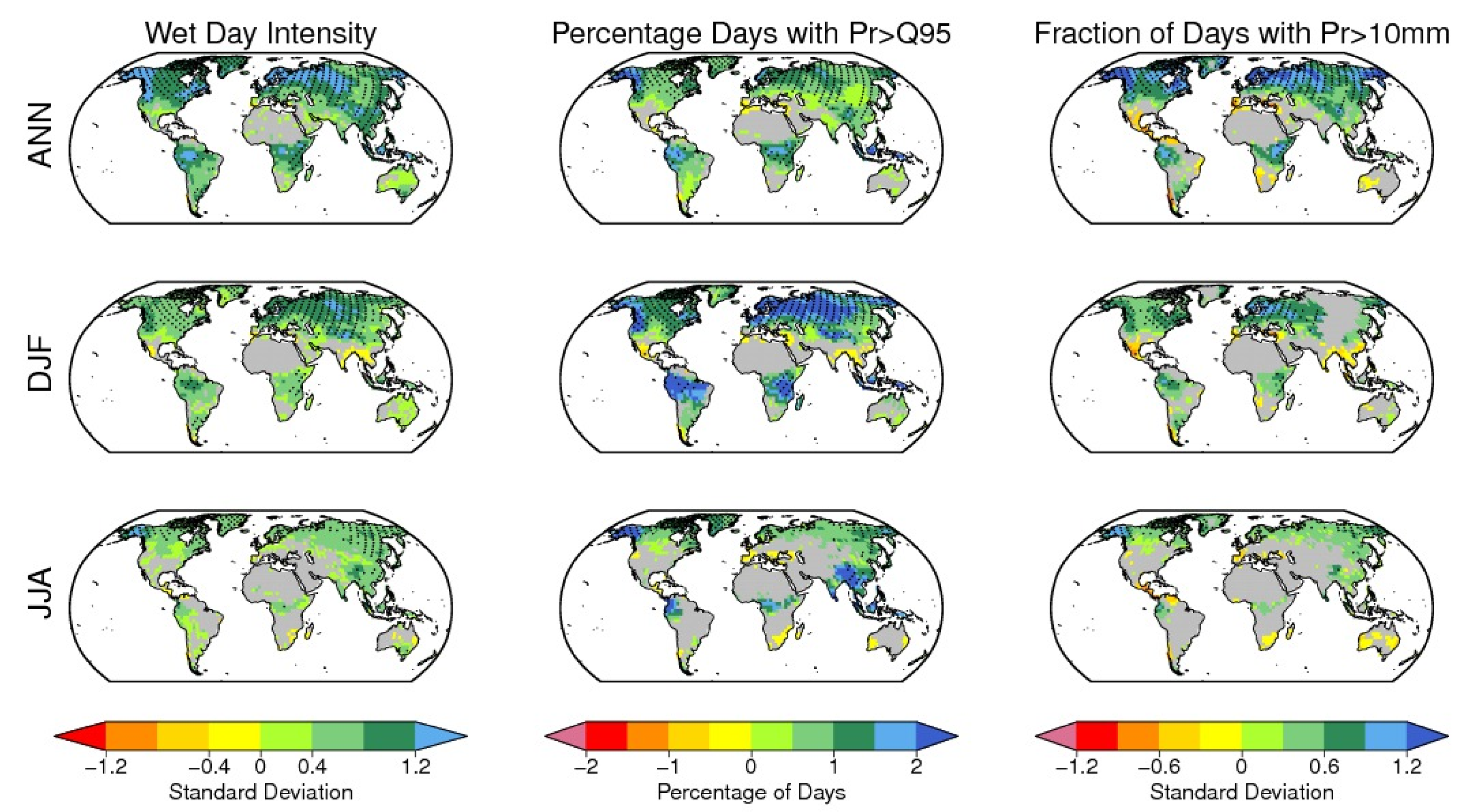

Fig. 3. Annual and seasonal changes (2081-2100 minus 1980-1999) of three indices for precipitation: Wet day intensity, fraction of days where precipitation exceeds the climatological 95%-ile and fraction of days where precipitation exceeds 10 mm.

Dryness extremes

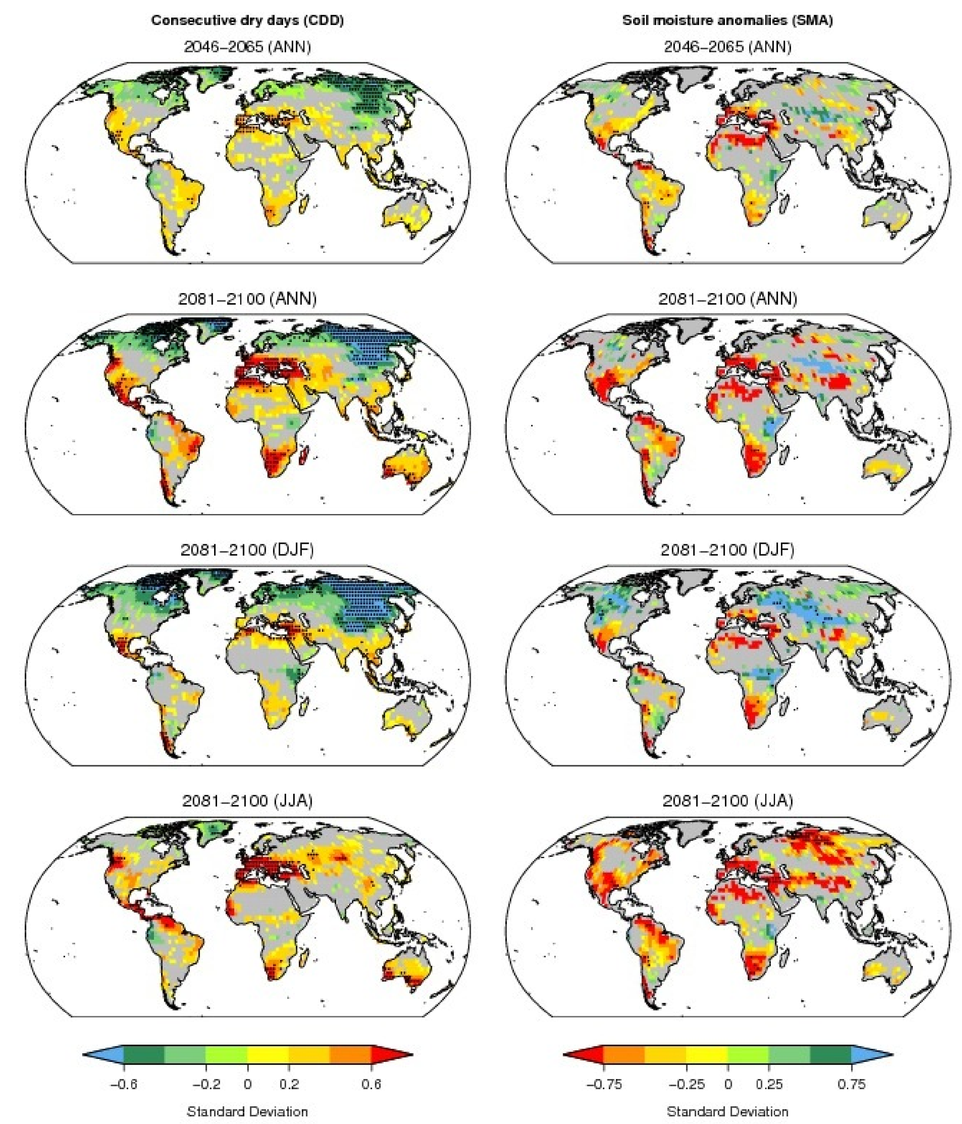

Fig. 4. Annual and seasonal changes (2081-2100 or 2046-2065 minus 1980-1999) of two dryness indices: Maximum length of consecutive dry days (CDD) and average soil moisture anomalies (SMA).

Results

Temperature extremes

- **Fig. 1** All analyzed indices show more heat and less cold extremes all over the globe and across all seasons. The GCMs show high agreement for these trends.
- **Fig. 2** Heat wave duration accordingly increases, however the geographical pattern depends on the chosen index.

Precipitation extremes

- **Fig. 3** Compared to temperature there is less agreement between the GCMs for trends of precipitation extremes. Regions with consistent signals include Northern high latitudes with increasing heavy precipitation and the Mediterranean with decreases. Different indices show an overall agreement.

Dryness extremes

- **Fig. 4** Precipitation based dryness (CDD) shows patterns which contrast extreme precipitation, e.g. with decreases over Northern high latitudes and drying over the Mediterranean (in particular in JJA). Soil moisture anomalies confirm the Mediterranean drying but show no or inconsistent signals w.r.t. CDD trends elsewhere.

Changes in $T_{\max}$ percentiles: Extreme, seasonal, regional and *global warming* (GW) components

$$\Delta Qxx = \underbrace{\underbrace{\frac{\Delta_{\mathrm{SEAS}}Qxx}{\Delta_{\mathrm{SEAS}}Q50}}_{f_{\mathrm{extr}}}\underbrace{\frac{\Delta_{\mathrm{SEAS}}Q50}{\Delta_{\mathrm{ANN}}Q50}}_{f_{\mathrm{seas}}}\underbrace{\frac{\Delta_{\mathrm{ANN}}Q50}{\overline{\Delta_{\mathrm{ANN}}Q50}}}_{f_{\mathrm{reg}}}}_{f_{\mathrm{tot}}}\,\mathrm{GW}$$

Percentile changes ΔQxx of $T_{\max}$ as a product of different contributions:

- **Fig. 5** f_{seas} in DJF contributes mainly in the Northern high latitudes; in JJA it contributes strongly e.g. in the Mediterranean
- **Fig. 6** Symmetric increases in both percentiles over the Arctic, mainly in DJF. In JJA, main increase over the Mediterranean in the 90%-ile (2×GW)

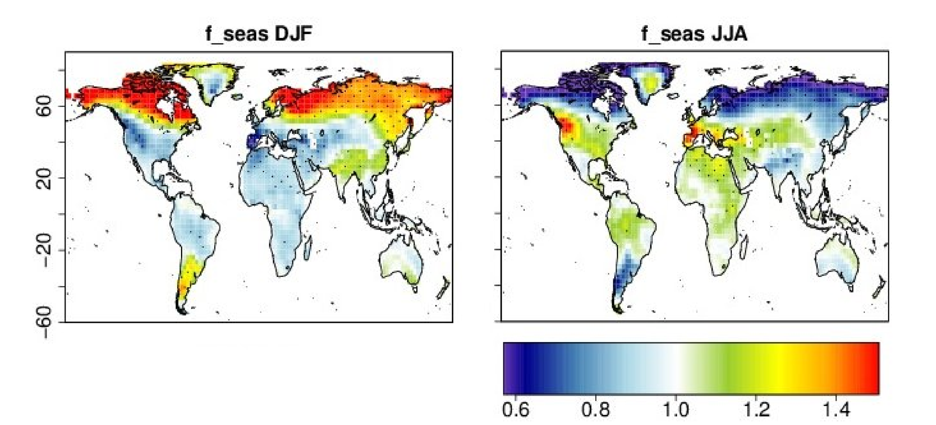

Fig. 5. Seasonal contribution f_{seas} to changes (2081-2100 minus 1980-1999) of the 10%- and 90%-ile of $T_{\max}$.

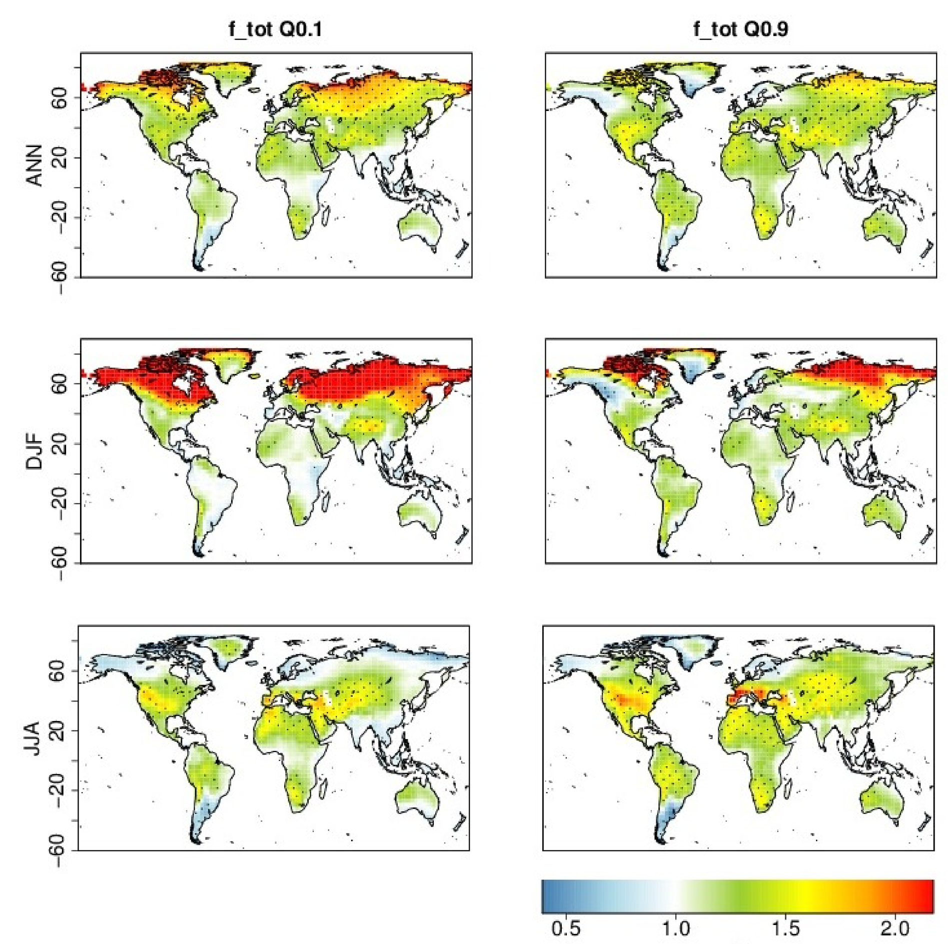

Fig. 6. Changes (2081-2100 minus 1980-1999) of the 10%- and 90%-ile of $T_{\max}$, scaled by global warming (f_{tot}).

Conclusions & Outlook

Our study provides a systematic overview of standard extreme event indices and their future trends in the presently most comprehensive ensemble of GCM simulations (IPCC AR4/CMIP3). It thereby complements previous work which was often limited to smaller ensembles [2]. The most immediate task is to apply similar analyses to the upcoming CMIP5 data. This will advance the robustness assessment of the identified trends and will provide a benchmark for extreme event analyses of model projections.

References

[1] B. Orlowsky and S. I. Seneviratne. Global changes in extreme events : Regional and seasonal dimension. *Clim. Change*, online first, 2011.

[2] Claudia Tebaldi, Katharine Hayhoe, Julie M. Arblaster, and Gerald A. Meehl. Going to the extremes - An intercomparison of model-simulated historical and future changes in extreme events. *Clim. Change*, 79(3):185–211, 2006.

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