Scaling and Intensification of Extreme Precipitation in Climate Change Simulations at Kilometer-Scale Resolution

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Link Between Temperature Change and Extreme Precipitation Change

Moistening of the atmosphere is determined by Clausius-Clapeyron relation:

$$\frac{1}{e_{sat}}\frac{de_{sat}}{dT} \approx 6-7\%/K \qquad \Longrightarrow \qquad \frac{1}{P_{extreme}}\frac{dP_{extreme}}{dT} \approx 6-7\%/K$$

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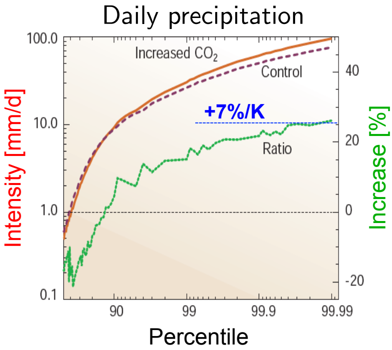

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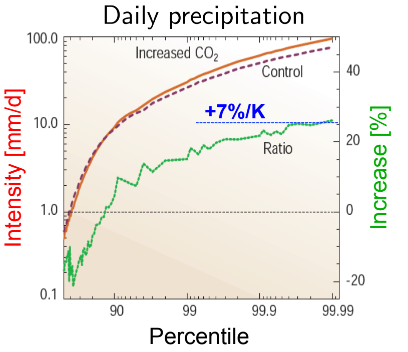

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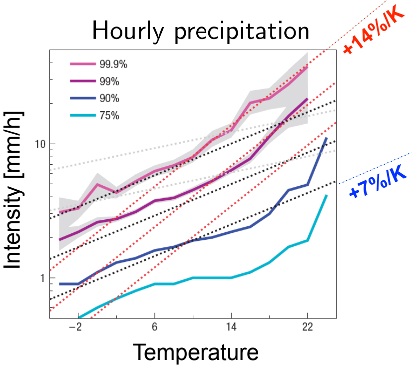

[Lenderink and van Meijgaard, 2008]

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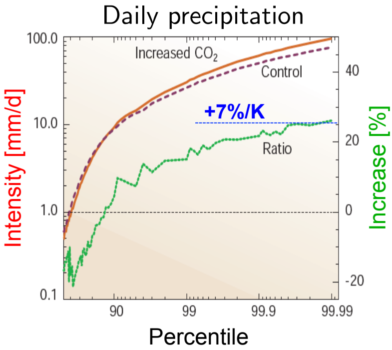

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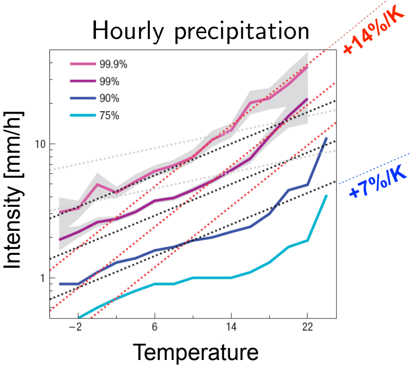
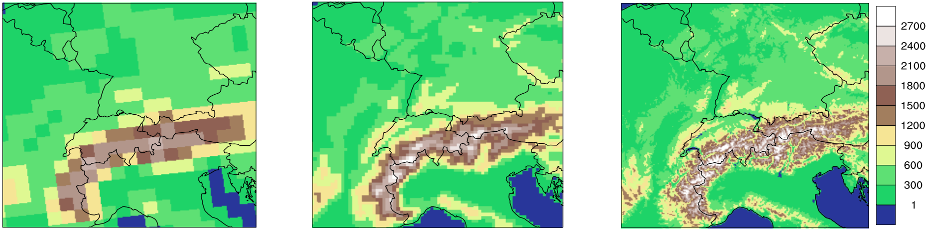


[Lenderink and van Meijgaard, 2008]

- Do heavy hourly precipitation events increase at adiabatic (~6-7 %/K) or super-adiabatic (~14 %/K) rate?

Numerical modeling of climate

Global climate model 50 km | Regional climate model 12 km | Convection-resolving model 2 km



- CRM: Convection-resolving model enables explicit simulation of convection (e.g., thunderstorms, rain showers)

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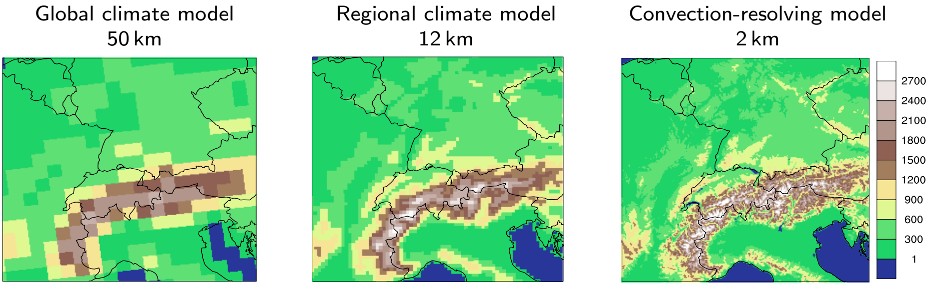

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- CRM studies: Grell et al., 2000; Mass et al., 2002; Hohenegger et al., 2008; Knote et al., 2010; Kendon et al., 2012, 2014; Langhans et al., 2013; Prein et al., 2013; Rasmussen et al., 2011, 2014; Ban et al., 2014, 2015; Prein et al., 2015 (Rev. of Geophysics), Kendon et al., 2016 (BAMS), Leutwyler et al., 2016

Outline

Evaluation

- Does CRM improve representation of precipitation distribution and statistics?
- How do precipitation extremes scale with temperature? With Clausius-Clapeyron relation?

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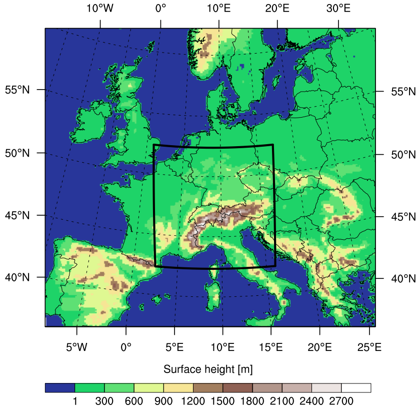
Climate Change

- Difference between CRM and conventional climate models?
- Link between temperature change & precipitation change?

Setup

Two-step one-way nesting: BC ⇒ CPM12 ⇒ CRM2

- CPM12 and CRM2 use COSMO-CLM v4.14
- Boundary Conditions: ERA-Interim reanalysis & MPI-ESM-LR (RCP8.5)
- CPM12: Convection–Parameterizing Model
  - $\triangle x,y = 12$ km (0.11°)
  - XxYxZ=260x228x60
- CRM2: Convection–Resolving Model
  - $\triangle x,y = 2.2$ km (0.02°)
  - XxYxZ=500x500x60



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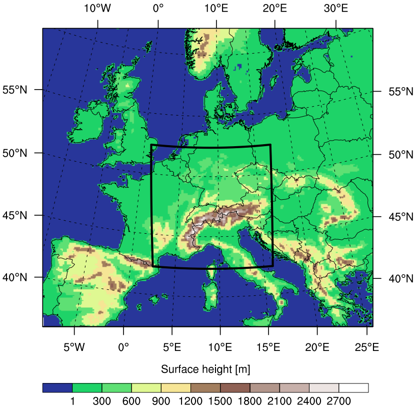

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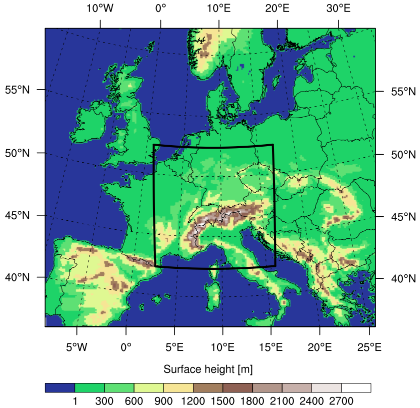
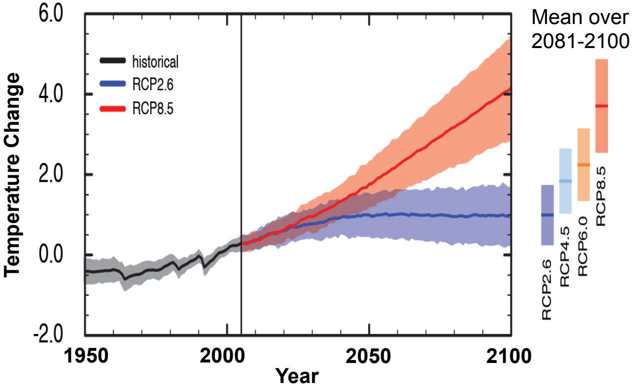


The numerical simulations have been performed on the CRAY XT5 and CRAY XE6 at the Swiss National Supercomputing Center (CSCS)

Experiments: CRM Simulations for the Greater Alpine Region



[IPCC AR5]

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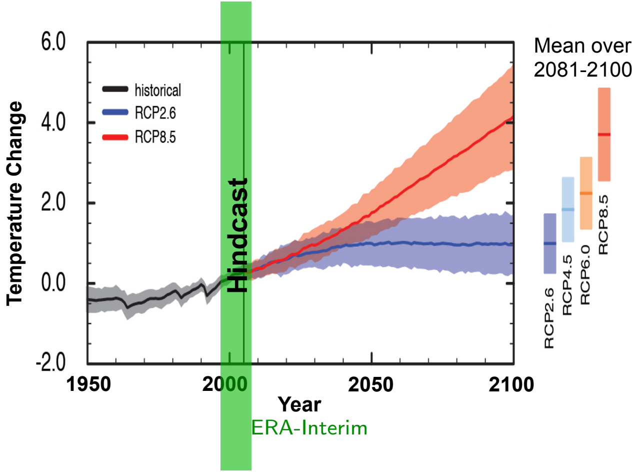

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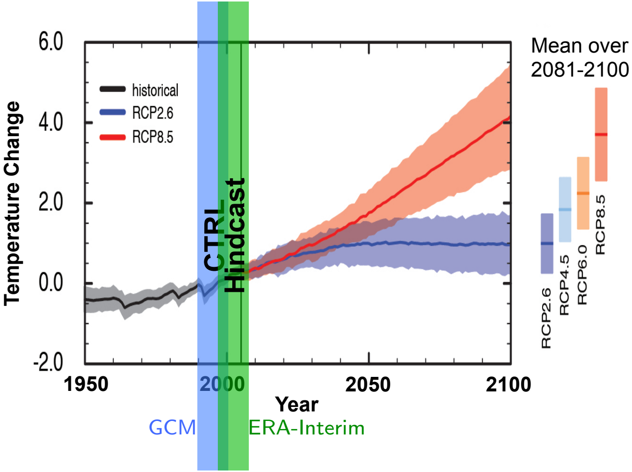

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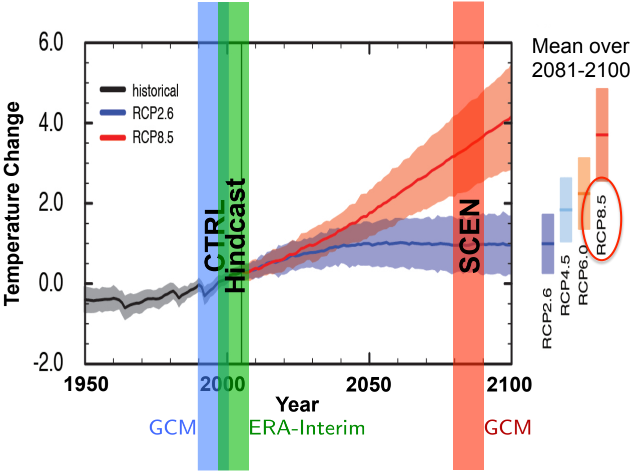

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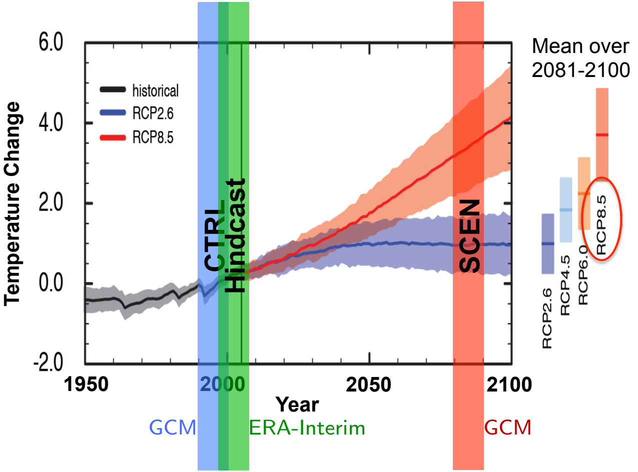


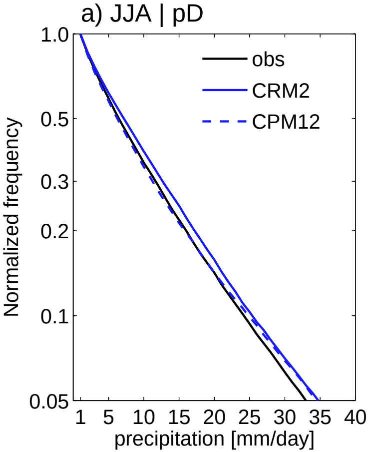
- Wallclock time: 1×10y CRM2 → ≈4-8months

[IPCC AR5]

Evaluation of Precipitation in Present-Day Climate

- ERA-Interim driven simulations (1998–2007)

Frequency-Intensity Distribution of Precipitation (JJA)



[Analysis for 62 Swiss stations]

(Ban et al., 2015 GRL)

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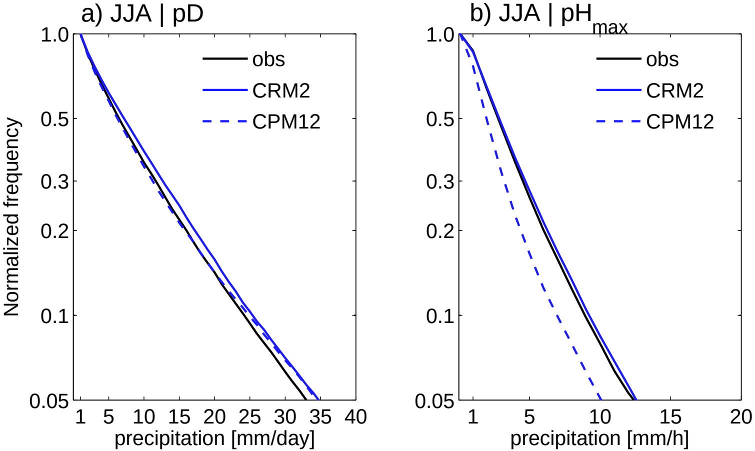

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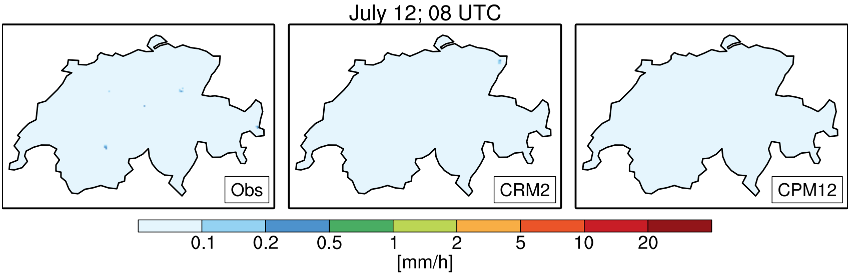
Evolution of the Hourly Precipitation (July 12-14, 2006)



Obs → Combined radar and rain gauge observations (Wüest et al., 2010)
CRM2 → Explicit convection ($\triangle$x,y=2.2km)
CPM12 → Parametrized convection ($\triangle$x,y=12km)

(Ban et al., 2014 JGR)

Evaluation of Precipitation – Average across 62 Swiss Stations

Summer (JJA)

	mean	freq1d	int1d	freq1h	int1h
Obs	4.11	0.38	10.8	0.12	1.41
CRM2	4.64	0.39	11.28	0.12	1.57
CPM12	4.43	0.41	10.55	0.15	1.21

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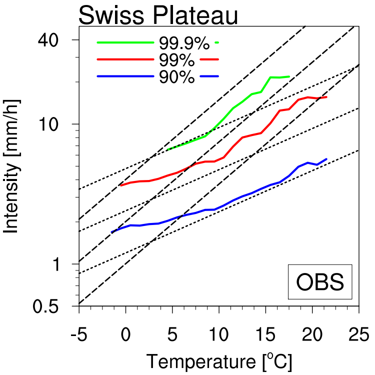
Winter (DJF)

	mean	freq1d	int1d	freq1h	int1h
Obs	2.31	0.28	8.12	0.13	0.73
CRM2	3.19	0.36	8.65	0.18	0.72
bias	38%	29%	6.5%	38%	-1.2%
CPM12	3.3	0.38	8.49	0.2	0.68
bias	43%	36%	4.5%	52%	-7.2%

→ CRM2 improves the simulation of precipitation in the winter (DJF) and summer (JJA) season

Scaling of Extreme Hourly Precipitation Events

··· 7% increase per °C (as Clausius-Clapeyron)
- - - 14% increase per °C



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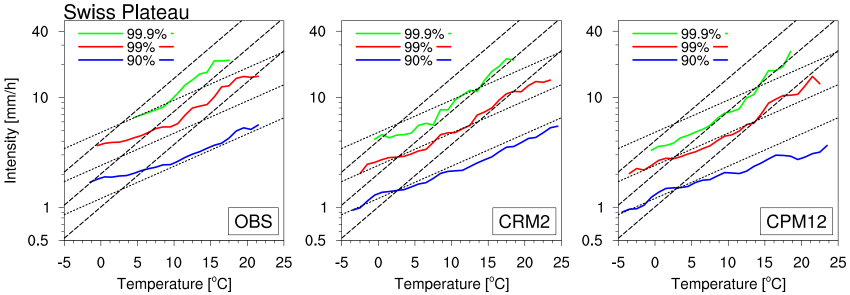


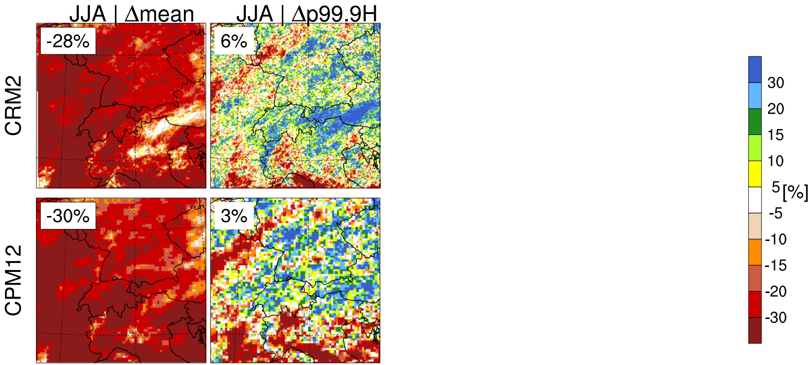
- Super-adiabatic scaling is captured by both models

(Ban et al., 2014 JGR)

Projections of precipitation

- based on GCM-driven scenarios for 2081-2090 (RCP8.5) versus 1991-2000

Projections of Mean and Heavy Precipitation



Summer (JJA):

- Increase in heavy precipitation despite an overall drying
- Decrease in large-scale, and increase in convective precipitation (Giorgi et al., 2016, Nature Geoscience)

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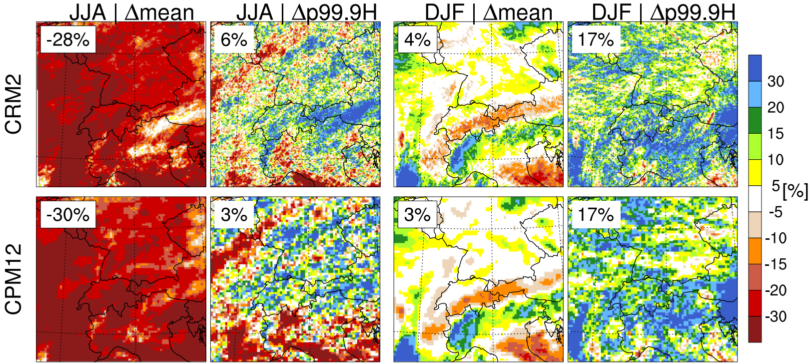

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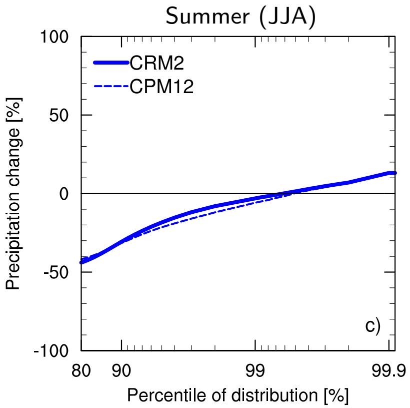
Winter (DJF):

- CRM2 and CPM12 show similar changes

Relative Changes of Precipitation on Daily Timescales



[Average across the CRM2 domain]

- Close agreement of CRM2 and CPM12

(Ban et al., 2015 GRL)

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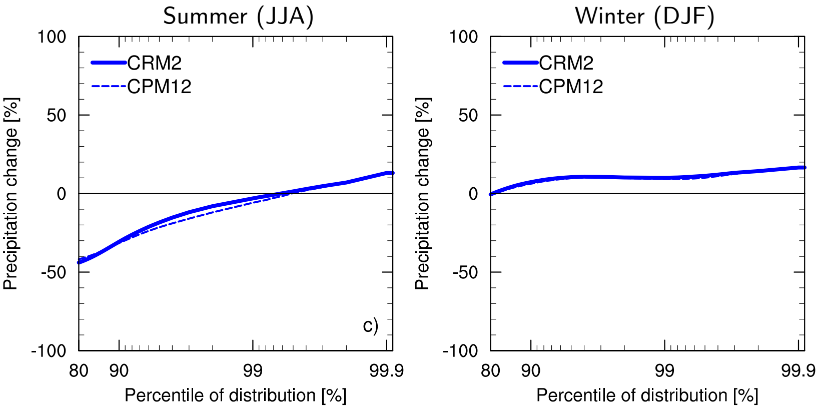

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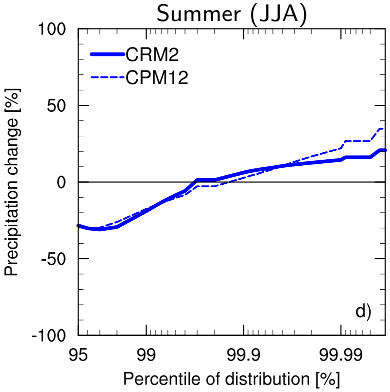

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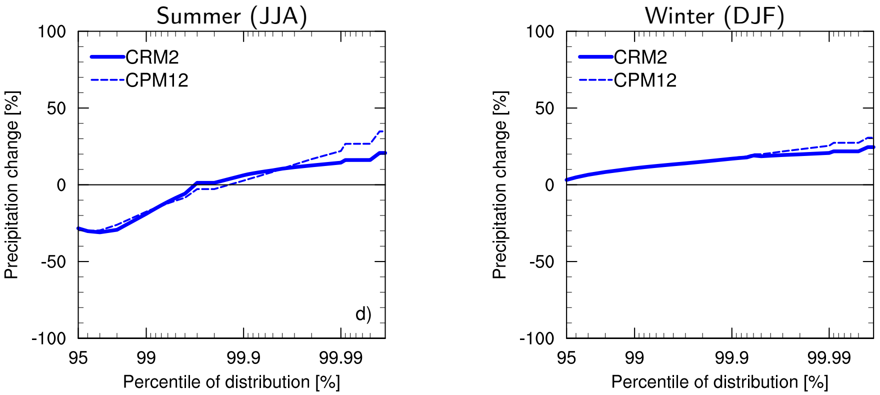

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- CRM2 exhibits smaller changes than CPM12

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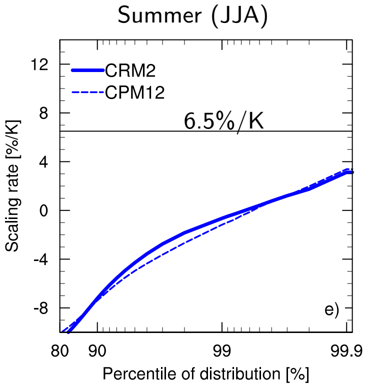

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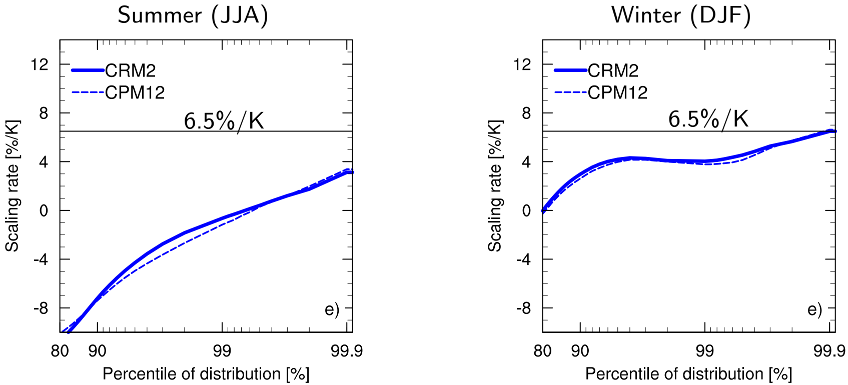

⇒ Extreme daily precipitation asymptotically intensify with the Clausius-Clapeyron relation

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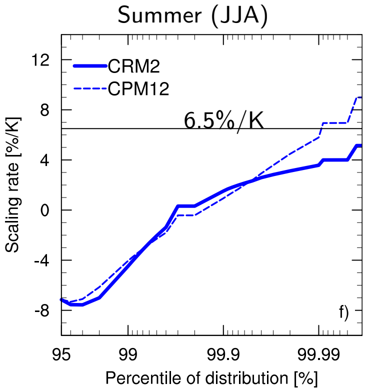
Link Between Temperature Change and Extreme Hourly Precipitation Change



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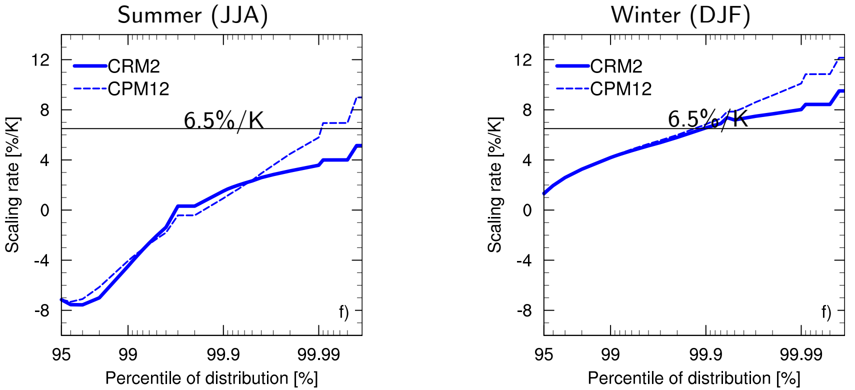

⇒ Summer (JJA): Extreme hourly precipitation asymptotically intensify with the Clausius-Clapeyron relation

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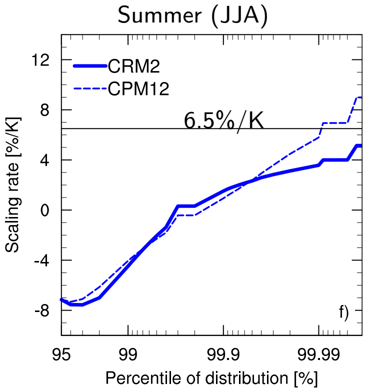

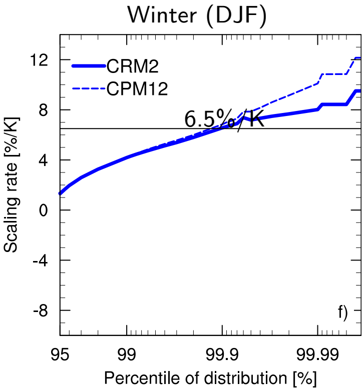

⇒ Summer (JJA): Extreme hourly precipitation asymptotically intensify with the Clausius-Clapeyron relation
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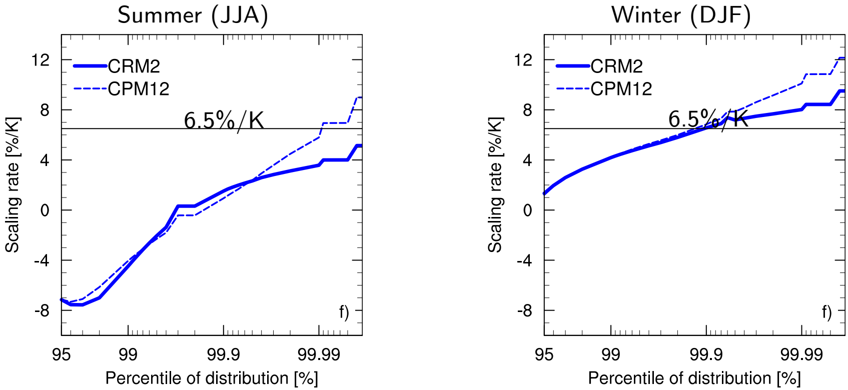

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Although...

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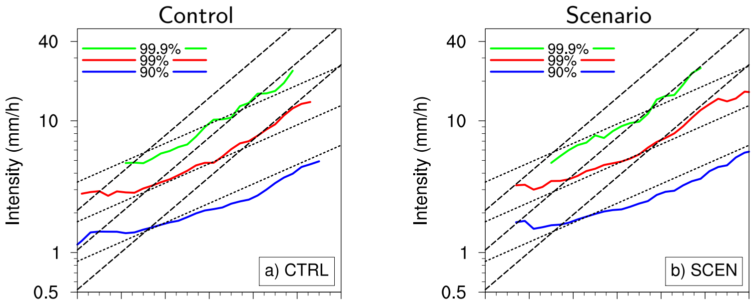

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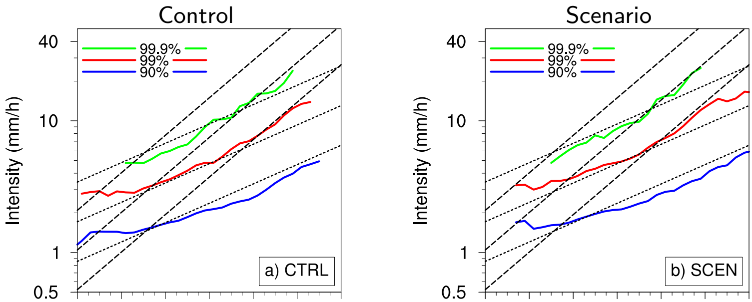

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⇒ Indicates that scaling of extreme precipitation with temperature in present-day climate can not be extrapolated into the future

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Summary

Evaluation

- CRM2 improves the simulation of precipitation in all seasons and on all time scales (especially on the sub-daily)
- CRM2 exhibits super-adiabatic and adiabatic scaling for hourly warm-season precipitation, while only adiabatic for hourly cold-season precipitation (in accordance with observations)

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- Close agreement of CRM2 and CPM12 regarding the changes in daily precipitation; for hourly extreme precipitation CRM2 exhibits smaller changes than CPM12
- Changes in extreme summer precipitation qualitatively scale with the Clausius-Clapeyron rate. In winter the change exceeds the Clausius-Clapeyron rate for short-term extreme precipitation

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Thank you for your attention!