Convection-resolving climate change simulations: Short-term precipitation extremes in a changing climate

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Hydrological Impacts of Heavy Precipitation

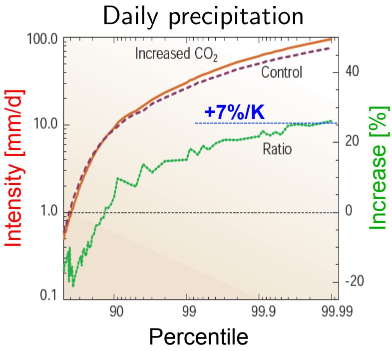
Flash floods

Saanen (Switzerland), Jul 2010

Landslides

Graubünden (Switzerland), Aug 2014

Link Between Temperature Change and Extreme Precipitation Change



[Allen and Ingram, 2002]

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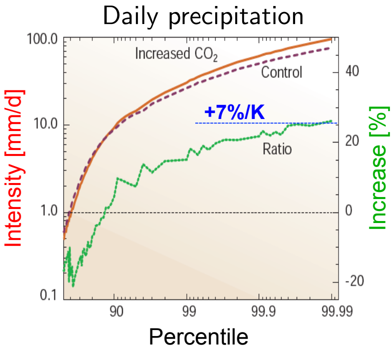

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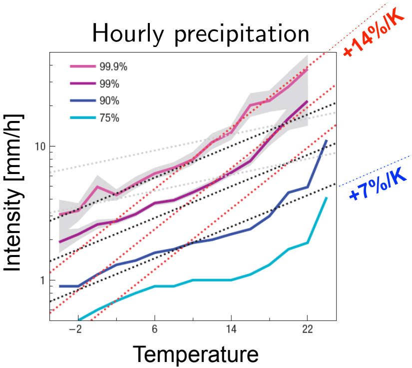
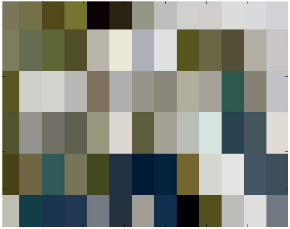


[Lenderink and van Meijgaard, 2008]

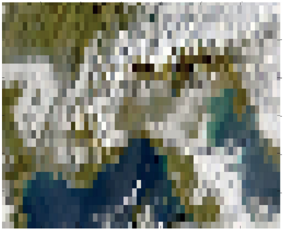
- Do heavy hourly precipitation events increase at adiabatic (∼6-7 %/K) or super-adiabatic (∼14 %/K) rate?

Numerical modeling of climate

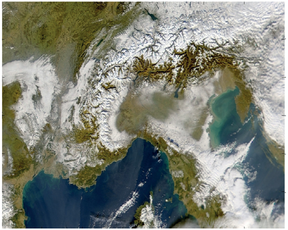
Global climate model
100 km



Regional climate model
25 km



Convection-resolving model
1 km



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

[Figures: E. Zubler]

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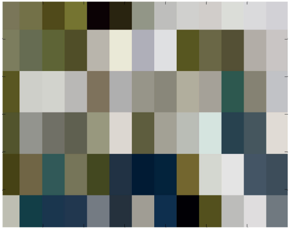

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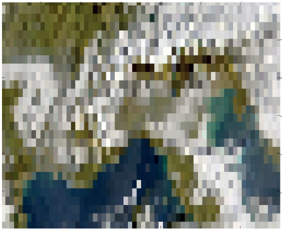

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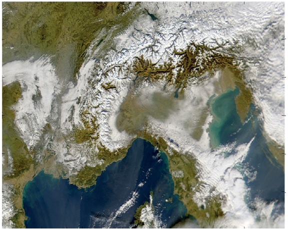


- CRM: Convection-resolving model enables explicit simulation of convection (e.g., thunderstorms, rain showers)
- CRM pioneering studies: Grell et al., 2000; Hohenegger et al., 2008; Knote et al., 2010; Kendon et al., 2012, 2014; Langhans et al., 2013; Prein et al., 2013; Rasmussen et al., 2014; Ban et al., 2014, 2015; Prein et al., 2015 (review paper), Brisson et al., 2016

[Figures: E. Zubler]

Objectives

Evaluation

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

Climate Change

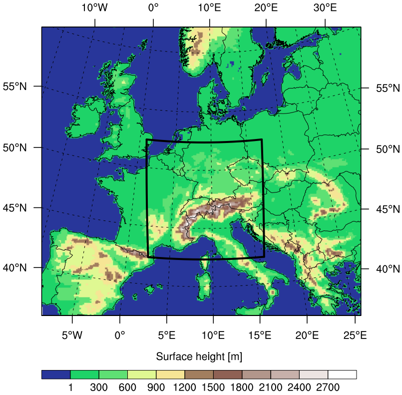
- Difference between CRM and conventional climate models?
- Link between temperature change & precipitation change?

Continental-scale convection-resolving climate simulations (crCLIM)

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
  - $\triangle x$=12 km (0.11°)
  - XxYxZ=260x228x60
- CRM2: Convection–Resolving Model
  - $\triangle x$=2.2 km (0.02°)
  - XxYxZ=500x500x60



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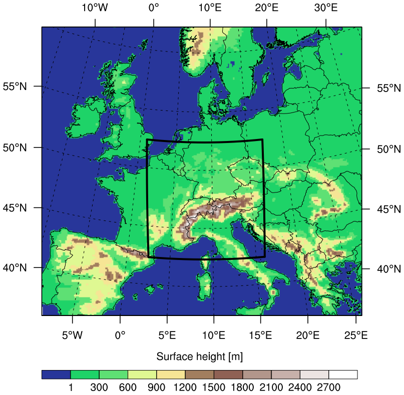

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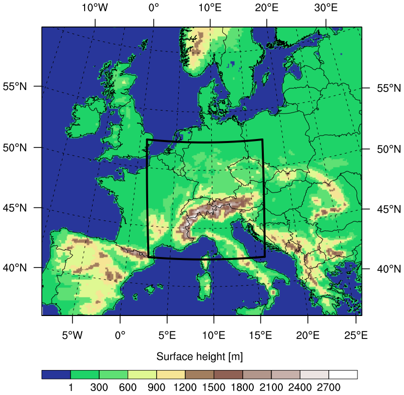
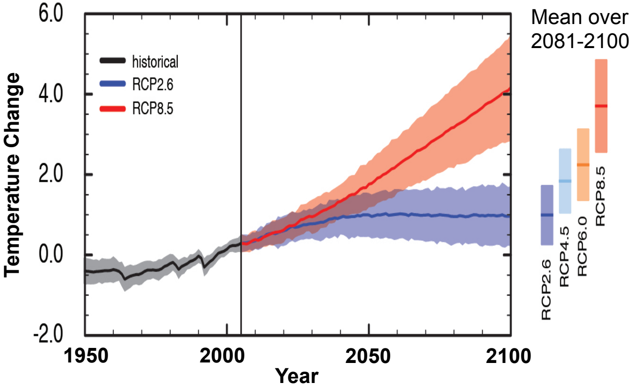


The numerical simulations have been performed on the CRAY XT5 and CRAY XE6 at CSCS

Experiments: CRM Simulations for the Greater Alpine Region



[IPCC AR5]

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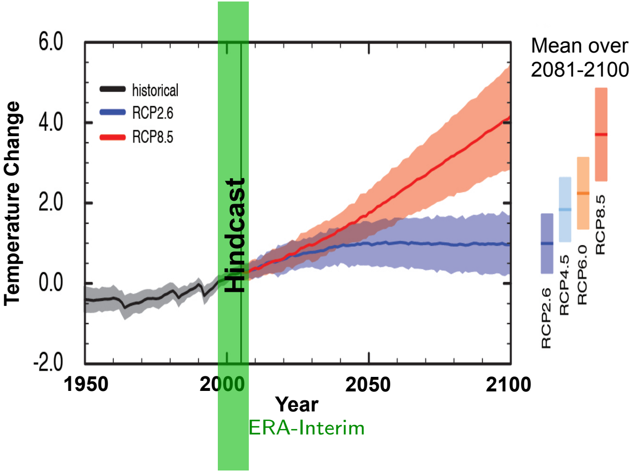

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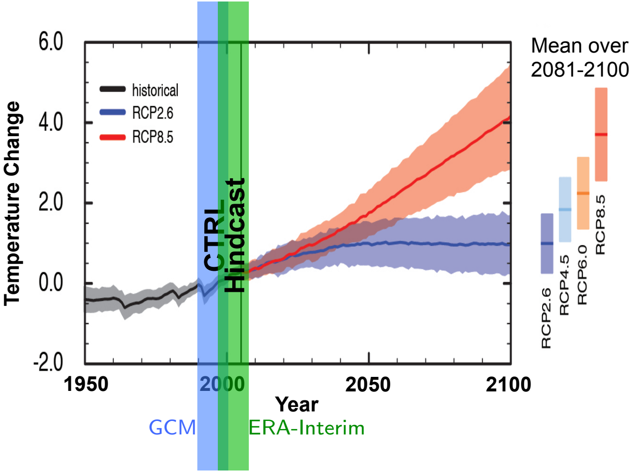

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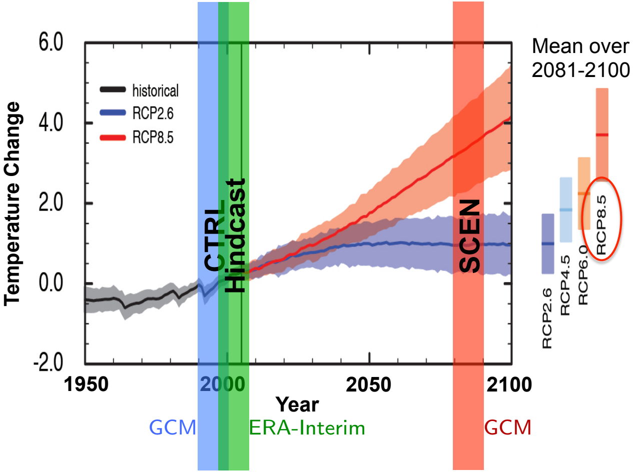

GCM ERA-Interim GCM

[IPCC AR5]

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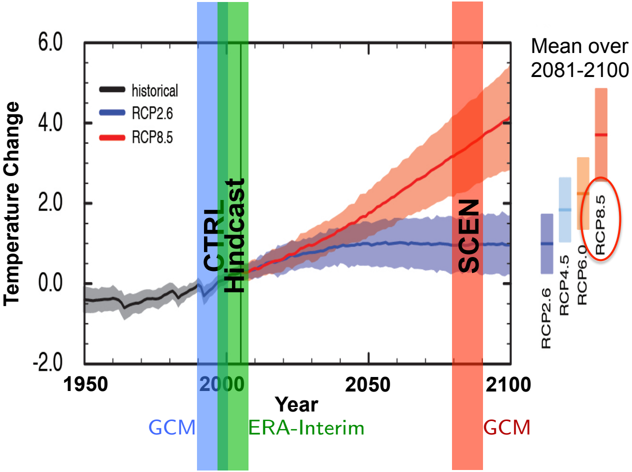


- Wallclock time: 1×10y CRM2 → ≈4-8months

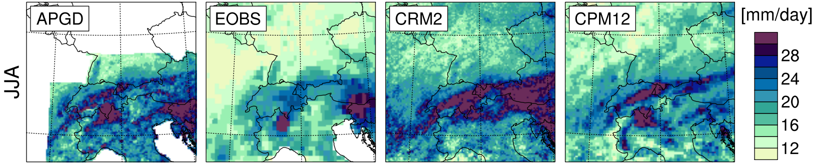
[IPCC AR5]

Evaluation of Precipitation in Present-Day Climate

- ERA-Interim driven simulations (1998–2007)

The 90th percentiles of daily/hourly precipitation in JJA

The 90th percentiles of daily precipitation



[Obs - APGD (Isotta et al., 2014), EOBS (Haylock et al., 2008) and RdisaggH (Wüest et al., 2010)]

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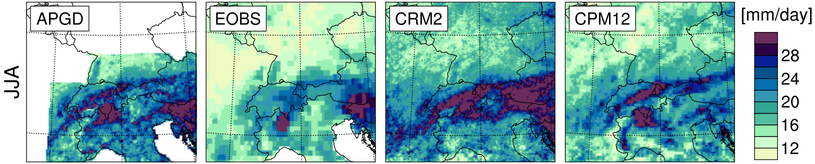
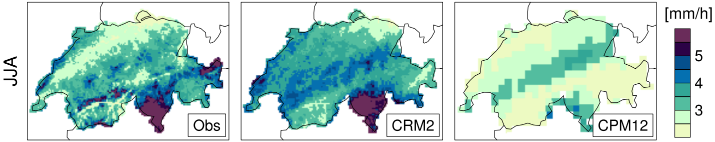


The 90th percentiles of hourly precipitation



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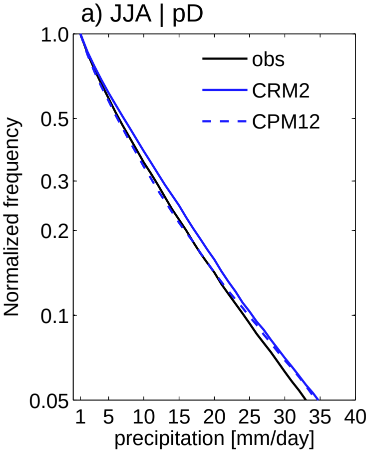
Frequency Distribution of Precipitation (JJA)



[Analysis for 62 Swiss stations]

(Ban et al., 2015 GRL)

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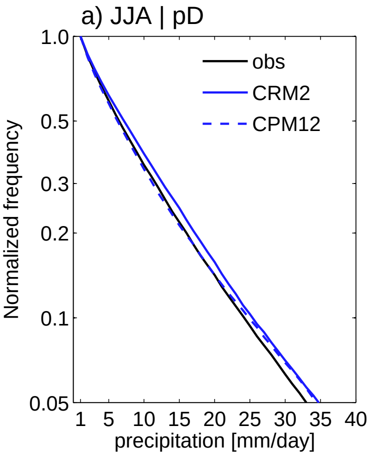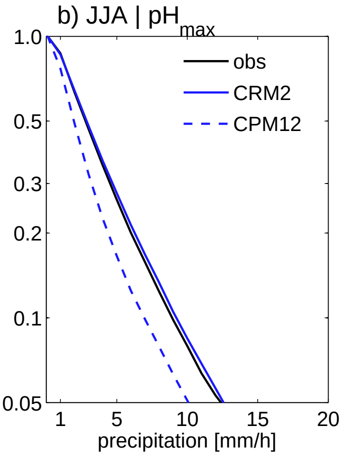

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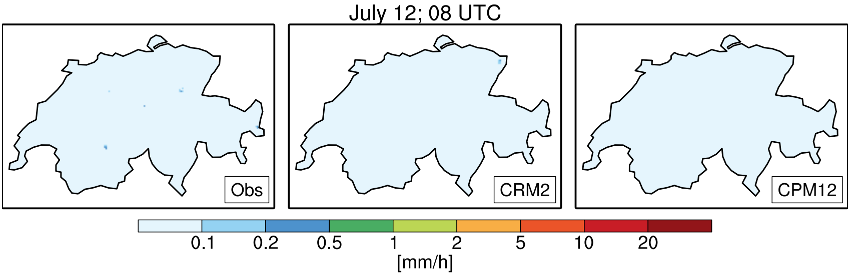
Evolution of the Hourly Precipitation (July 12-14, 2006)

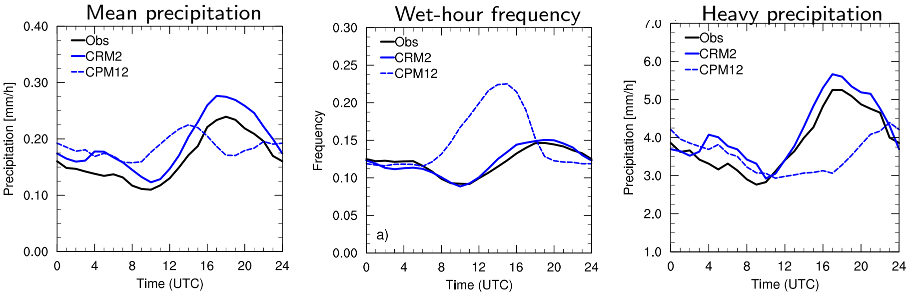

July 12; 08 UTC

|◁ < ◁ ▷ > ▷| − ⋈ +

Obs → combined radar and rain gauge observations (Wüest et al., 2010)
CRM2 → explicit convection ($\triangle$=2.2km)
CPM12 → parametrized convection ($\triangle$=12km)

(Ban et al., 2014 JGR)

Diurnal Cycle of Summer Precipitation



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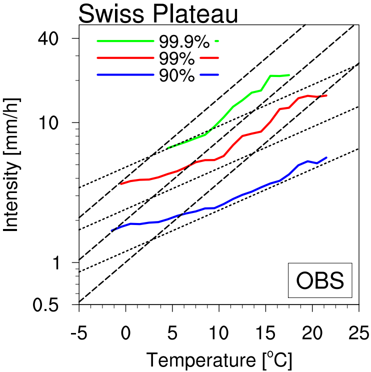
- CRM2 realistically simulates amplitude and phase of the diurnal cycle

(Ban et al., 2015 GRL)

Scaling of Extreme Hourly Precipitation Events

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



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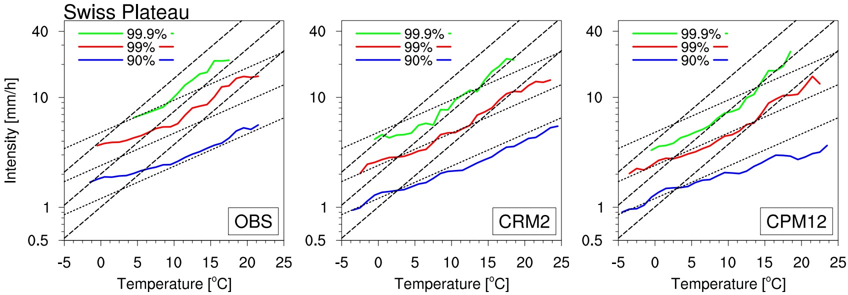


- Super-adiabatic scaling captured by both models

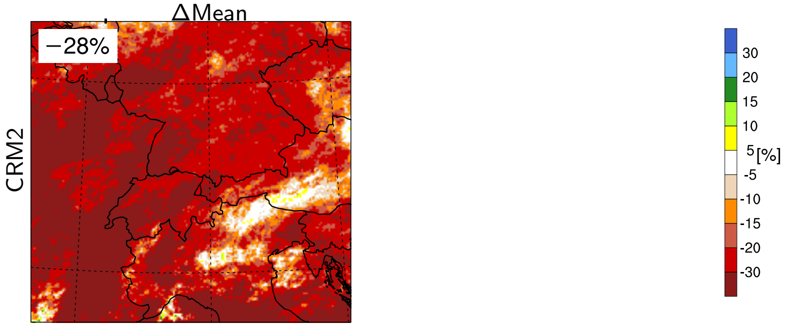
(Ban et al., 2014 JGR)

Projections of precipitation

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

Summer precipitation

Relative change → $\frac{SCEN-CTRL}{CTRL}$

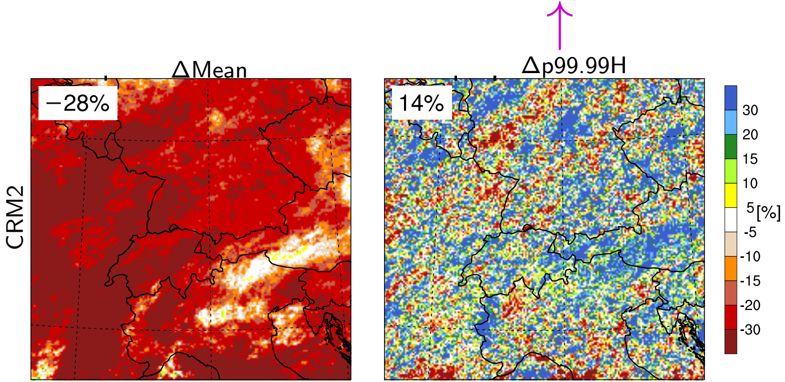


(Ban et al., 2015 GRL)

Summer precipitation

Relative change → $\frac{SCEN-CTRL}{CTRL}$

2 events per 10 seasons

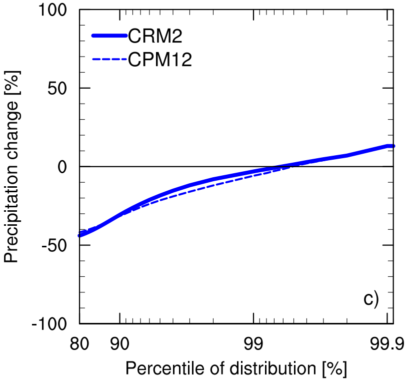


- Increase in extreme precipitation despite an overall drying

(Ban et al., 2015 GRL)

Summer Precipitation on Daily Timescales

Relative change in percentile intensities → (SCEN-CTRL)/CTRL

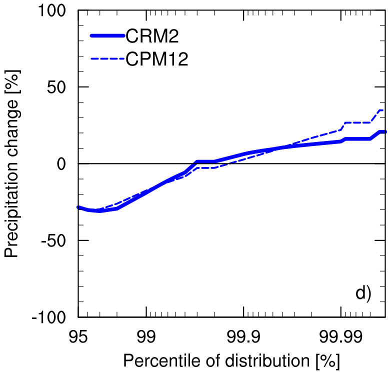


[Average across the CRM2 domain]

- Close agreement of CRM2 and CPM12

(Ban et al., 2015 GRL)

Summer Precipitation on Hourly Timescales



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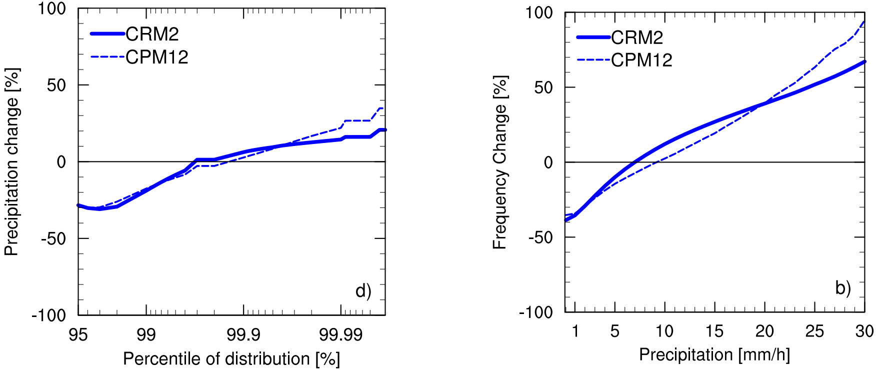

[Average across the CRM2 domain]

- CRM2 exhibits smaller changes than CPM12

(Ban et al., 2015 GRL)

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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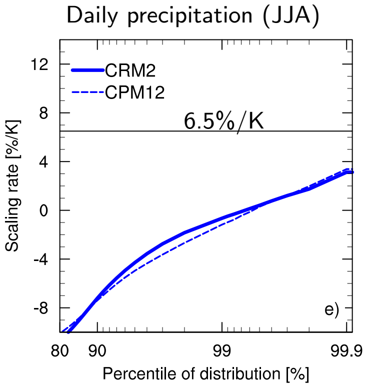

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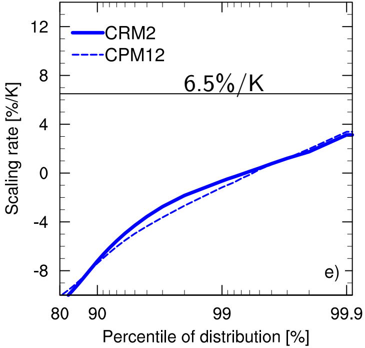
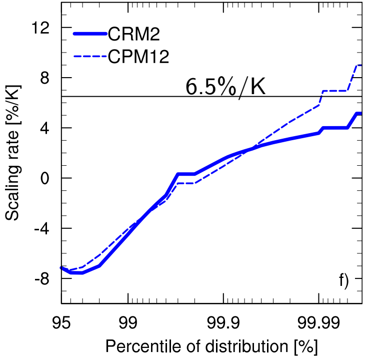

Daily precipitation (JJA)


Hourly precipitation (JJA)

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

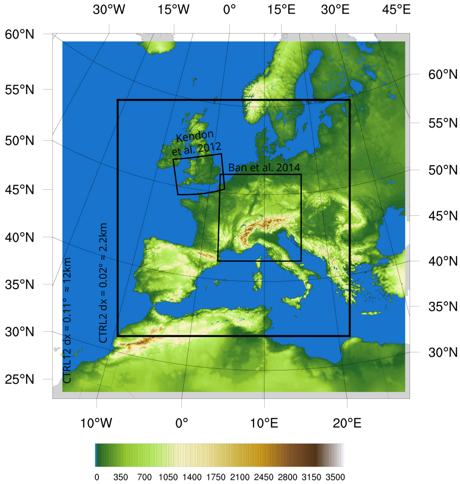
- Assessment uses all-event percentiles (Schär et al., 2016)(Ban et al., 2015)

Convection-Resolving Climate Modeling on Future Supercomputing Platforms (crClim)

`http://www.c2sm.ethz.ch/research/crCLIM.html`

European-Scale Convection-Resolving Climate Simulations (crClim)

- Two-step one-way nesting: ERA-Interim ⇒ 12km ⇒ 2.2km
- 1536×1536×60 grid points
- 10-year long period: 1999-2008 ⇒ Completed
- Wall-clock time: 1 year ⇒ 5 days
- GPU version of COSMO (Fuhrer et al., 2014)



(Leutwyler et al., 2016 Submitted to GMD)

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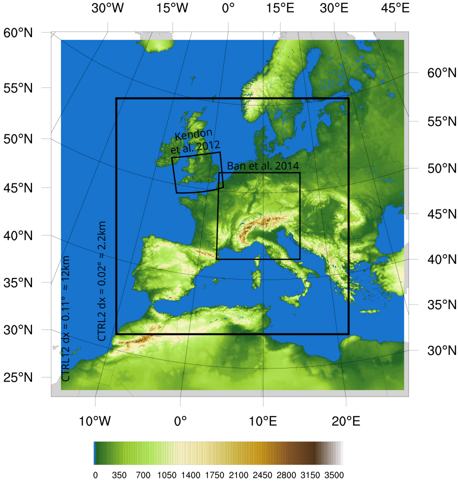
- GPU version of COSMO (Fuhrer et al., 2014)
    - Dynamical core rewritten in C++
    - Parameterizations use OpenACC
    - Runs on Piz Daint (Cray XC30, CSCS)
    - Used for operational NWP at MeteoSwiss (Δx=1 km)



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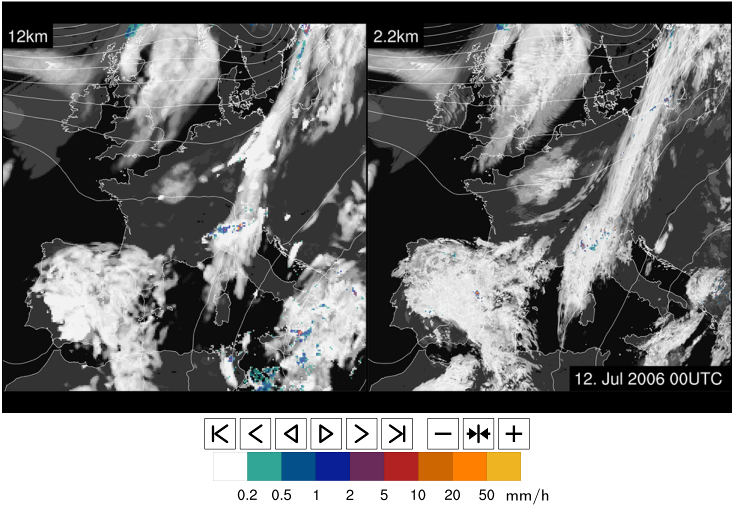

(David Leutwyler)

Summary

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Thank you for your attention!